A STUDY OF THE EFFECTS OF VARYING RATES OF LOADING ON THE CONSOLIDATION OF SOIL

ROBERT K. WHITE

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by

Robert K. White

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Approved:

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Adviser

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FOREWORD

From his first introduction to the subject of soil mechanics, one is impressed most, perhaps, by the profusion of unknown or questionable factors involved in accurately predicting soil behavior. For this reason, attempts at formulization of these unknowns are of primary interest. This impression, more than any other factor, served as a stimulus for undertaking the investigation reported in this thesis.

The author would like to express his appreciation to Assistant Professor Robert L. Schiffman who, as adviser, aided greatly in the setting up and conduct of the experimental program.

In addition, the author is indebted to the Division of Soil Mechanics, headed by Professor E. J. Kilcawley, for their very able and courteous assistance both by providing hints and suggestions and also by making available the facilities of the entire section. This assistance was invaluable.

ABSTRACT

In order to predict more accurately the settlement of structures, many approaches to the theory of consolidation have been made. The most famous of these is the Terzaghi theory. The limitations of this theory as associated with construction loading have been recognized by Schiffman in his approach to a mathematical solution. Marron initiated investigations into the validity of Schiffman's work, and it is the purpose of this investigation to further these studies.

Testing was carried out on two types of apparatus. The first one, a standard, two-position static loading device, was utilized during three series of tests including a usual incremental test, a large incremental test, and a small incremental test.

The second apparatus consisted of a Conbel loading device which was operated by air pressure regulated through a valve which in turn was connected to an opening mechanism. This opening mechanism consisted of a geared-down electric motor whose output rate could be varied by a belt-and-pulley arrangement to the valve stem. Thirteen test runs at varying rates were conducted with this device.

Permeability readings were conducted throughout testing by use of a constant head permeameter developed by Marron.

The material used throughout testing was a pure kaolinite clay, the inclusion of which it was hoped would eliminate many of the inconsistencies encountered in a natural soil. Thus, results would be that much more easily interpreted.

The results of this experimentation show that there is a definite effect upon total strain and void ratio change by imposition of different loading conditions. It can definitely be seen that large increments and more rapid loading rates cause larger deformation.

For the static tests it was seen that larger permeabilities were experienced at the same porosity when large increments were applied than when small increments were applied.

During the time dependent loading tests, the results failed to show any definite relationship between permeability and porosity, though the fact that there was a spread of values leads to speculation that further, more intensive study along this line would be warranted.

It is concluded that as far as the scope of this study has investigated, Schiffman's approach to the consolidation of soil under conditions of time-dependent loading and varying permeability is valid.

PART I.

INTRODUCTION

A. Objective

The purpose of a study of soil mechanics is to be better able to predict the behavior of soil under varying conditions encountered in the field. One aspect of soil behavior quite important in all construction is the process of consolidation and just how much settlement can be expected after the construction takes place and a load is applied.

The studies by Dr. Karl Terzaghi in this field are almost universally followed. However, many investigators have recognized certain shortcomings therein and have attempted to extend Terzaghi's theory with modifications to take care of these shortcomings.

Very recent work by Assistant Professor Robert L. Schiffman of Rensselaer Polytechnic Institute has presented a mathematical solution to consolidation under conditions of time-dependent loading and varying permeability. It is considered that such conditions more accurately approximate actual field situations.

It is the avowed purpose of this study to conduct a series of consolidation tests under various rates of loading. Perhaps, not as a direct result of these tests alone but after a period of extended study, Schiffman's and/or similar approaches can be completely validated. Thus, the practice of soil mechanics will become more nearly a science.

B. Historical Review

Dr. Karl Terzaghi, in one of his works (9) states that in 1856 Tyndall discussed "partially consolidated mud" in his "Fragments of Science". For the next few decades work done in the direction of consolidation was mostly as connected with agriculture. However, to illustrate that the problems of consolidation were still being studied by the pioneers in the field, Collingwood (1) in 1891, at a lecture presented at Rensselaer Polytechnic Institute, stated that subsurface exploration should be carried out to such a depth as to preclude the possibility of the presence of a compressible layer.

However, all of these statements and all the empirical formulae previously developed were shoved into obscurity when in 1925 Dr. Terzaghi (8) published his "Theory of Consolidation". For the first time engineers had at their disposal a quantitative method of predicting consolidation under loading. Since 1925 there have been innumerable treatises either extending, criticising, or upholding Dr. Terzaghi's work (2, 3, 5, 6, 10), but to this day his theory is still the basis of all work in the field.

The most questionable of Dr. Terzaghi's original assumptions, however, is that of instantaneously applied loading, and although graphical approximations to time rates of loading and total settlement have been developed, there has been no rigorous mathematical solution to the problem.

Schiffman (5) has attempted this mathematical approach recently, and Marron (4) initiated laboratory work in an attempt to justify Schiffman's approach. In this work, the author intends to further these studies of Marron.

PART II.

THEORY

A. General

It is generally acknowledged that the most valid theory of consolidation of soils is that proposed by Dr. Karl Terzaghi (8) in 1925. There is actually little point in bringing forth any theory introduced prior to this time. Since this important contribution of Dr. Terzaghi, however, there have been certain modifications and extensions proposed (5, 7) and it might be well to mention them.

Further, although it is understood that many volumes of theory could be included as being pertinent, the author has no intention of restating much of the fundamental work which is readily available in almost any standard textbook on soil mechanics.

B. Theory of Terzaghi

The assumptions stated by Dr. Terzaghi in the presentation of his theory are as follows:

1. Homogeneous soil
2. Voids of the soil are completely filled with water
3. Water and solid constituents of soil are completely incompressible
4. Darcy's law is strictly valid
5. The coefficient of permeability K is a constant
6. The time lag of consolidation is due entirely to the low soil permeability
7. The clay is laterally confined
8. Both the total and effective normal stresses are the same for every stage of the process of consolidation
9. An increase in the effective pressure from an initial value $\bar{p}_o$ to a final value $\bar{p}$ reduces the void ratio of the clay from an initial value e_o to a final value e. The ratio

$$a_{vc} = \frac{e_o - e}{\bar{p} - \bar{p}_o}$$

is assumed a constant for the range of pressure $\bar{p}_o$ to $\bar{p}$. a_{vc} is called the coefficient of compressibility.

Using these assumptions and considering a layer

of clay buried beneath a bed of highly permeable sand with a uniformly distributed surcharge instantly applied to the surface of the sand (Figure 1), Dr. Terzaghi developed the following differential equation:

$$\frac{\partial u}{\partial t} = \frac{K}{\gamma_\omega m_{vc}} \frac{\partial^2 u}{\partial Z^2}$$

in which,

$u =$ excess pore pressure

$t =$ time

$K =$ the coefficient of permeability

$\gamma_\omega =$ the unit weight of the water

$m_{vc} = \frac{a_{vc}}{1+e_0} =$ the coefficient of volume decrease

$Z =$ vertical distance

For simplification, the relation

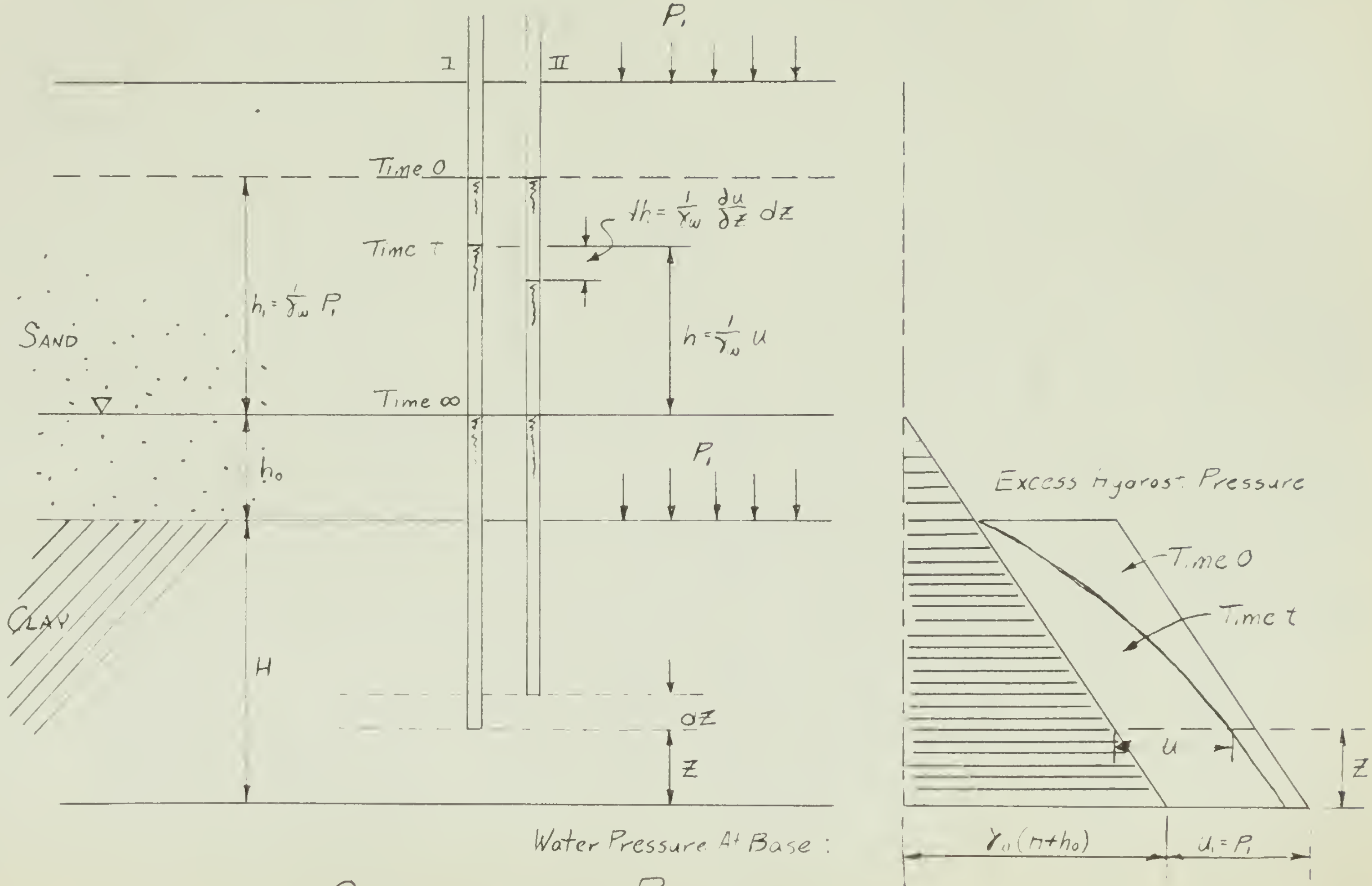
$$\frac{K}{\gamma_\omega m_{vc}} = C_{vc}$$

where C_{vc} becomes the coefficient of consolidation.

It is interesting to note that the process of consolidation as brought forth by Dr. Terzaghi has been shown to have mathematical analogues with the following physical processes: heat transfer, diffusion of substances dissolved in liquids, diffusion of gases, propogation of electric currents in cables, and movement of solid bodies through a stationary viscous liquid. (9)

For the boundary conditions stated and by use of Fourier's series, Dr. Terzaghi's differential equation leads to the following equation:

$$u = \frac{4}{\pi} p_1 \sum_{N=0}^{N=\infty} \frac{1}{2N+1} \sin\left[\frac{2(N+1)\pi Z}{2H}\right] \epsilon^{-(2N+1)^2 \pi^2 T_v/4} \qquad (1)$$



CONSOLIDATION PROCESS

Figure 1

The relationship

$$T_v = \frac{c_v}{H^2} t = \frac{K}{\gamma_\omega m_v} \times \frac{t}{H^2}$$

represents an independent variable called the "time factor".

However, the ultimate purpose of the theory is to predict settlement.

The decrease $d\rho$ of the thickness of a horizontal layer of original thickness dz is:

$$d\rho = \Delta n\, dz = m_v(p_1 - u)\, dz$$

Therefore settlement ρ at time t is:

$$\rho = \int_0^H \Delta n\, dz = m_v\left(p_1 H - \int_0^H u\, dz\right) \qquad (2)$$

Substituting this value in equation (1) and integrating results in:

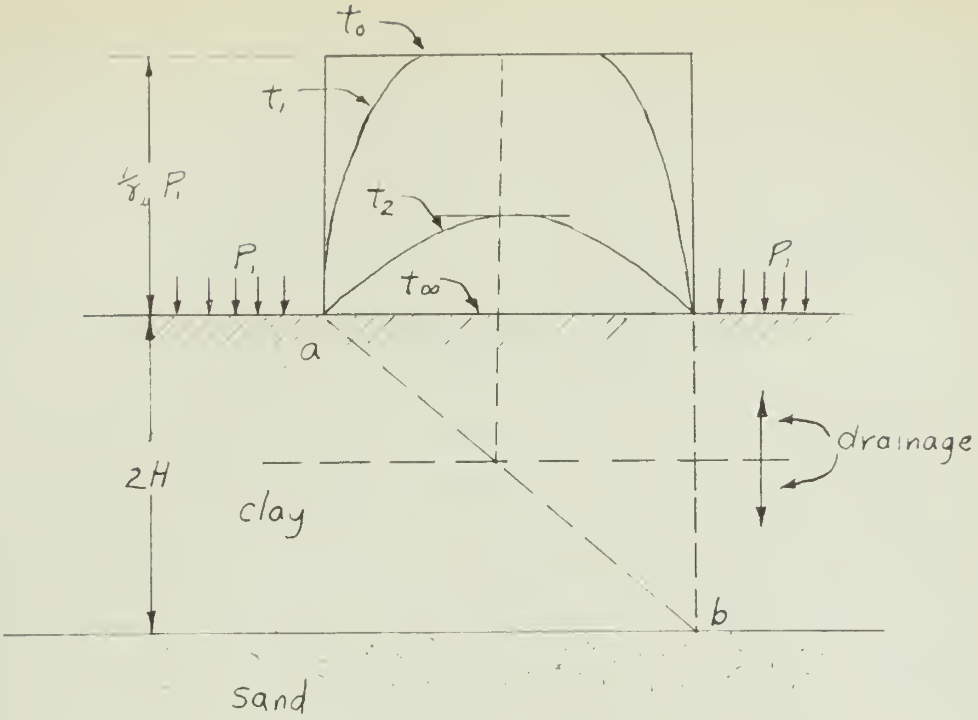
$$\rho = m_v p_1 H\left[1 - \frac{8}{\pi^2} \sum_{N=0}^{N=\infty} \frac{1}{(2N+1)^2} \epsilon^{(-2N+1)^2 \pi^2 T_v/4}\right] \qquad (3)$$

it can be seen that the factor outside the brackets represents the ultimate settlement, for as time t approaches infinity, the right-hand side of the relationship in brackets approaches zero.

However, it is not necessary in most cases to go through all these computations, since Terzaghi and Frohlich (9) plotted a family of curves (Figure 2) to approximate various loading conditions. Thus the process of predicting a reasonable value of settlement at a particular time is greatly simplified. First, the ultimate settlement is computed using the relationship:

$$\rho_1 = H m_v p_{avg}$$

Next, the time factor T_v is calculated, and using this in



Consolidation of clay layer afer sudden application of uniformly distributed surcharge. Curves show locus of water level in vertical piezometric tubes whose lower ends are located on $\overline{ab}$.

Figure 2

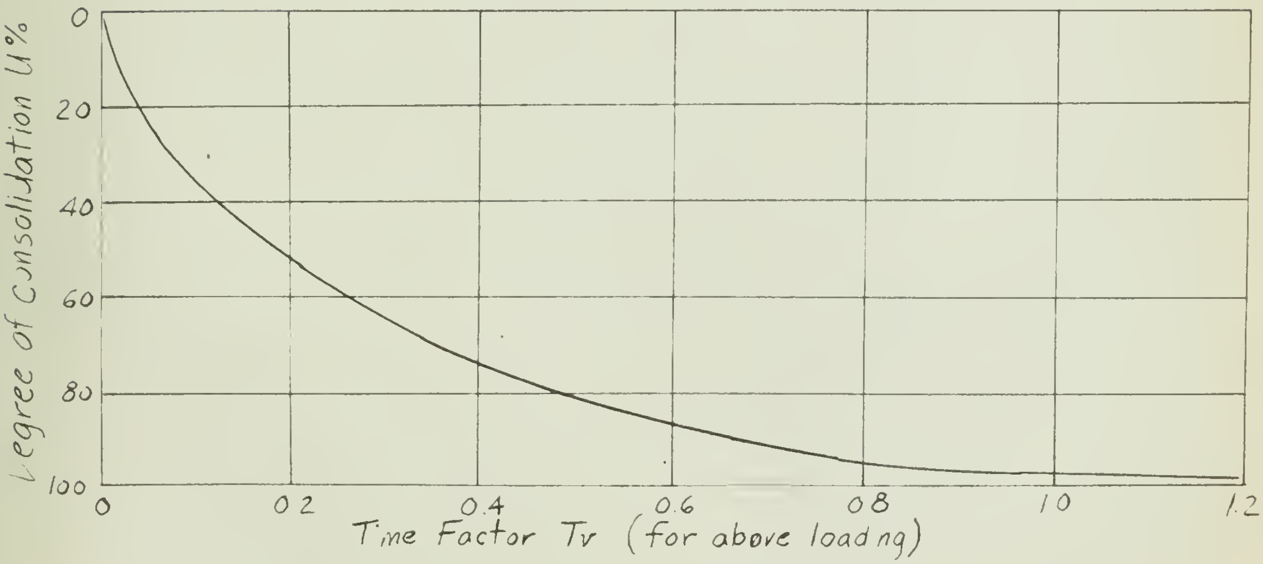


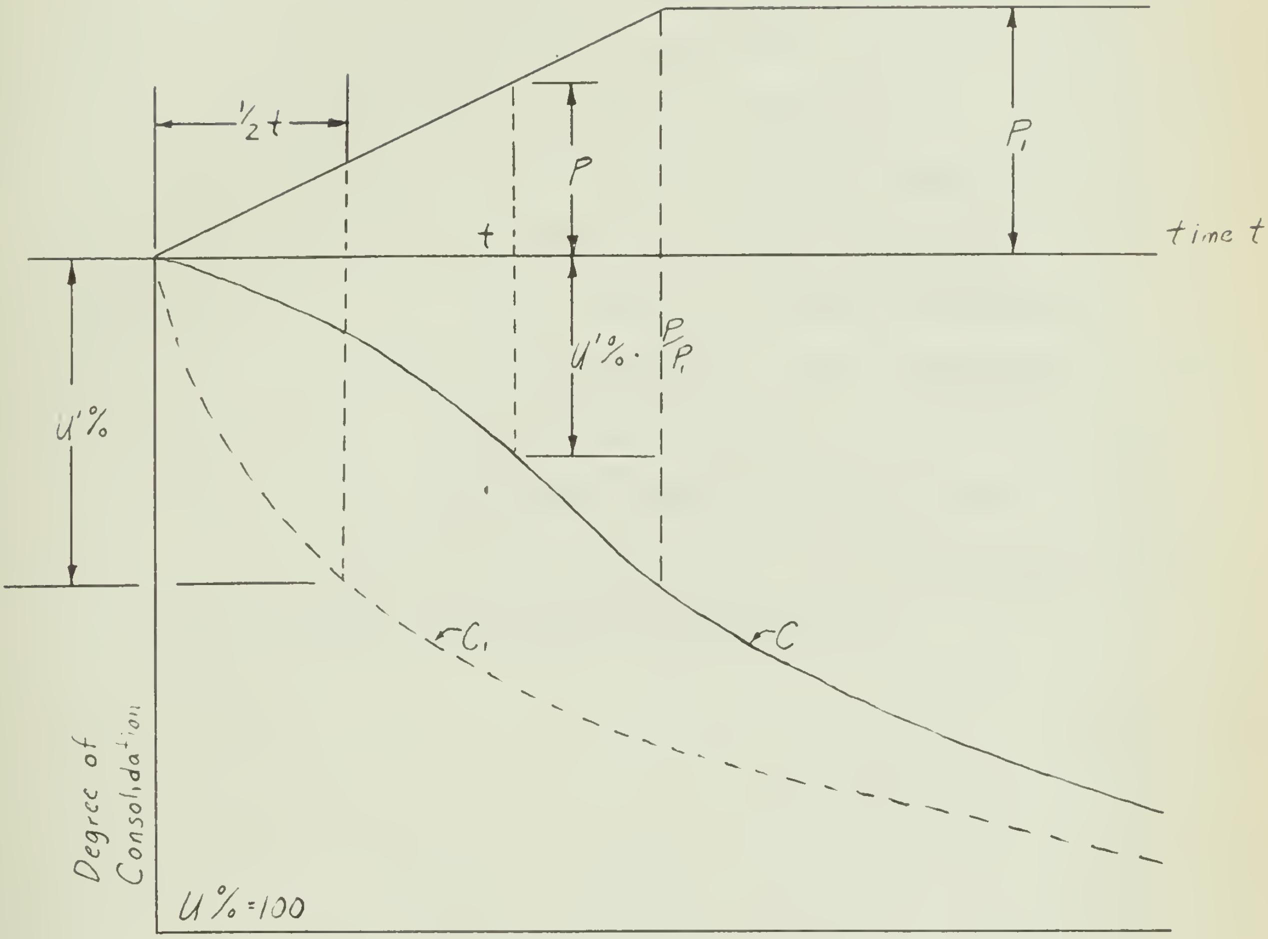
Figure 3

the chart of time factor versus degree of consolidation (Figure 3) a value of U% is arrived at.

Therefore, the settlement at the particular time t is merely

$$\rho = \rho_1 \left(\frac{U\%}{100} \right)$$

However, one important fact has been overlooked thus far. Very seldom in the field is a load instantaneously applied and not subsequently increased. Recognizing this fact, Terzaghi and Frohlich (9) developed a graphical method. This is pictured in Figure 4. The phenomenon of linear load increase is exemplified, but other conditions of gradual load application are set forth in Terzaghi and Frohlich (9).



Graphic method of determing time factor under gradually applied consolidation load.

Figure 4

C. Research by Taylor

D. W. Taylor published in 1942 (7) the results of several years' study of the consolidation of clays. The outcome of the studies was an indication that settlement predictions based upon the data of conventional consolidation tests are likely to be seriously in error unless the increments of load for the test and the actual structure are essentially alike. In other words, the research indicated that the consolidation relationship is not independent of the loading increment as Dr. Terzaghi's theory indicates. In conclusion, Taylor (7) stated that his results were conclusive enough to show that a need existed for more study into the factors which vary during consolidation.

D. Extension to Theory by Schiffman

Schiffman presents in (5) a mathematical approach to the condition of time-dependent loading and varying permeability of soil. His basic assumptions are:

1. Soil mass is completely saturated, the fluid incompressible, and the soil is of incompressible particles of small size
2. Darcy's law is instantaneously valid
3. The change in volume is small as compared to the original volume and is linear

Next he develops a differential equation of the general theory of consolidation with varying permeability and time-dependent loading and presents it in three forms as follows:

$$(1)\quad a\nabla u^2 + \nabla u \cdot \nabla K_f + a_u \nabla^2 u + K_f \nabla^2 u + Q\gamma_\omega = m\gamma_\omega \frac{\partial u}{\partial t}$$

$$(2)\quad \frac{1}{a}(\nabla K)^2 - \frac{1}{a}(\nabla K\ \nabla K_f) + \frac{1}{a} K \nabla^2 K - \frac{1}{a} K \nabla K_f + Q\gamma_\omega = \frac{m\gamma_\omega}{a}\frac{\partial k}{\partial t}$$

$$(3)\quad \nabla K_o \nabla u - a(\nabla U_o - \nabla u) + a(\nabla u)^2 + au\nabla^2 u + (K_o + aU_o)\nabla^2 u + Q\gamma_\omega = m\gamma_\omega \frac{\partial u}{\partial t}$$

However, the condition most closely approximated by the standard consolidation test is so-called one-dimensional consolidation. Under one-dimensional consolidation the following working conditions are evident:

(1) doubly drained clay layer

(2) clay layer of finite thickness

(3) clay layer infinite in width and breadth

(4) loading on the surface is infinite in extent

(5) the initial coefficient of permeability is uniform throughout clay layer

(6) initially imposed excess pore pressure is uniform throughout clay layer

Using these limiting conditions, the differential equation becomes:

$$\left[C_0 + \frac{a u_0}{m \gamma_w}\right] \frac{\partial^2 u}{\partial z^2} - \frac{a}{m \gamma_w} u \frac{\partial^2 u}{\partial z^2} - \frac{a}{m \gamma_w} \left(\frac{\partial u}{\partial z}\right)^2 + R = \frac{\partial u}{\partial t}$$

in which

$R =$ rate of change of imposed excess pore pressure

$C_0 =$ coefficient of consolidation at beginning of consolidation

PART III.

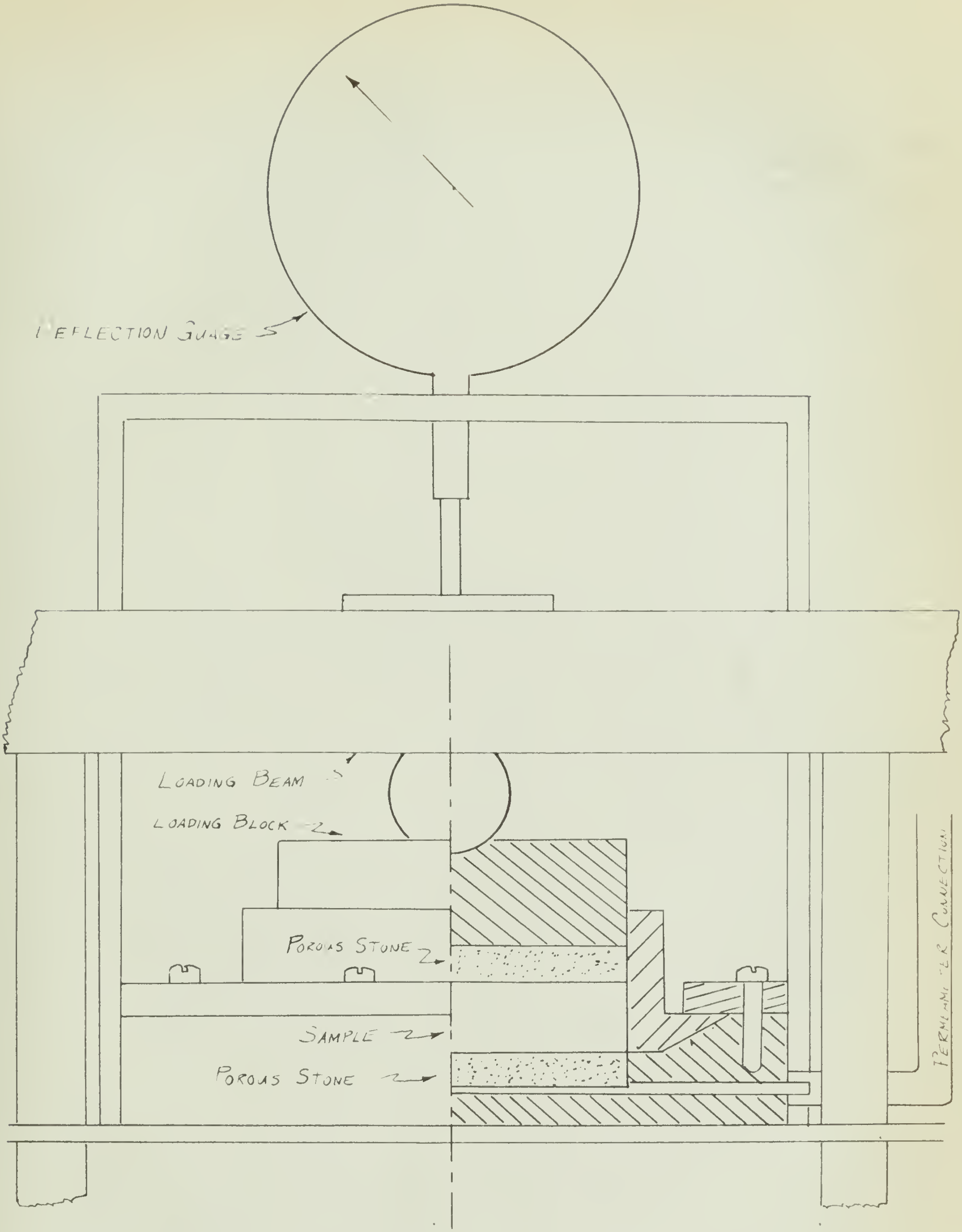
MATERIALS AND APPARATUS

The soil samples used during this investigation were prepared from pure kaolin clay received from Ward's Natural Science Corporation, Rochester, New York. The sample designation was "Kaolinite--Dry Branch Ga. Dana #492". An attempt to magnify the permeability readings by using samples composed of 50% kaolin and 50% of a sifted silt was abandoned when it was discovered that the readings were virtually unchanged.

Throughout the testing program a standard 2½" fixed ring consolidometer as shown in Figure 5 was used. The sample was separated from the porous stones by filter paper sheets which tended to prevent clogging the pores of the stones.

Loading during the static tests was applied by use of a Soil-Test Model C-280 beam loading device which afforded two positions for running duplicate tests.

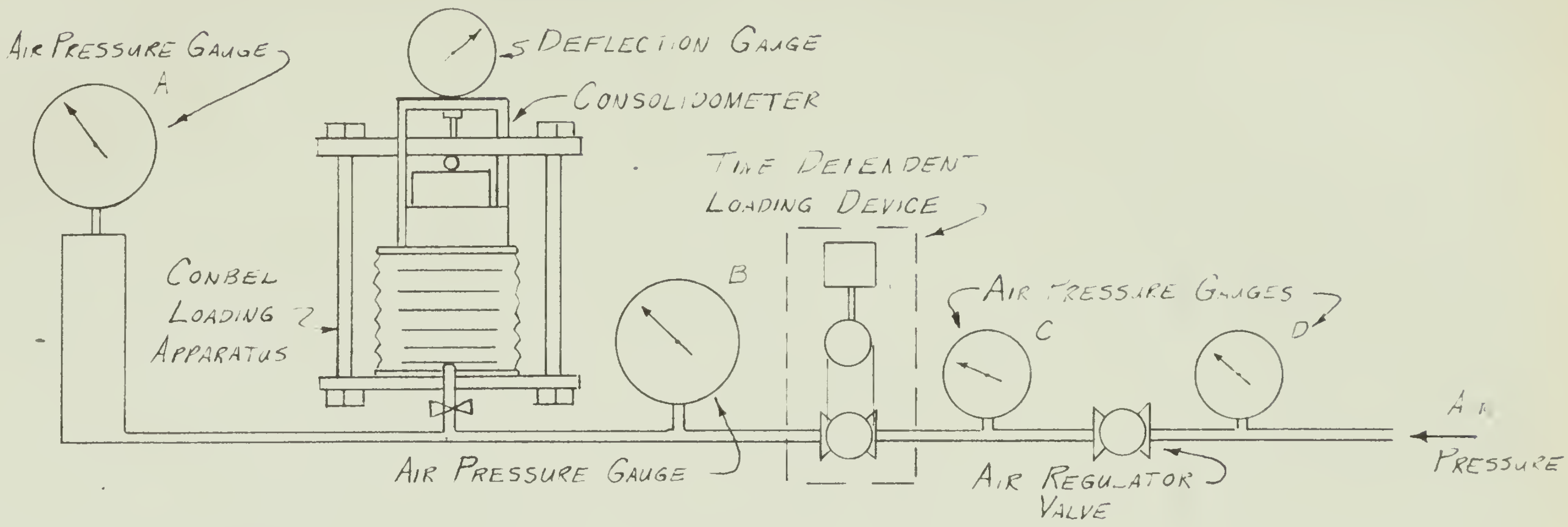
Loading during the continuous loading test was applied by use of a Conbel Model 350 as shown in Figure 6. This apparatus was adapted to continuous loading by placing a Conoflow regulator valve in the line supplying air pressure to the pressure accumulator of the Conbel equipment. This valve was gradually opened by means of a belt and pulley arrangement connected to a gear train and driven by a



STANDARD FIXED RING CONSOLIDOMETER (FULL SCALE)

Figure 5

CONTINUOUS LOADING DEVICE



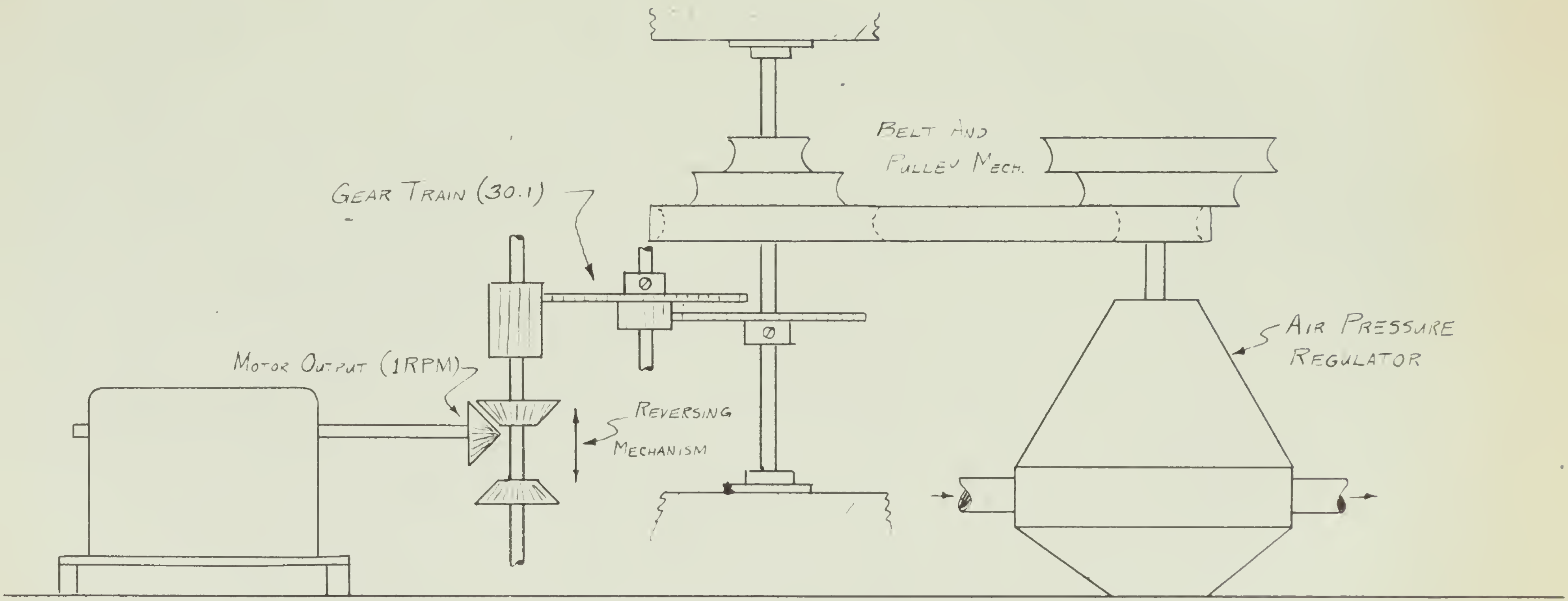
OPERATING PROCEDURE

1. Close Air Regulator Valves
2. Turn On Air Pressure.
3. Open Air Regulator Valve To Set Maximum Air Pressure Desired on Gauge C.
4. Set Time-Dependent Loading Device So That Gauge B Reads Zero.
5. Insert Consolidometer in Conbel Apparatus, Take Up Lost Motion Between Loading Head And Consolidometer, Set Deflection Gauge To Zero.
6. Start Time-Dependent Loading Device, At Times t Read Air Pressure on Gauge A While Checking Against Gauge B, And Read Deflection Gauge.

Figure 6

Holtzer-Cabot electric motor (9 watt--75 oz.-in. torque) as shown in Figure 7, which in turn was geared down to one revolution-per-minute. Various rates-of-opening the valve were obtained by varying the pulley ratios.

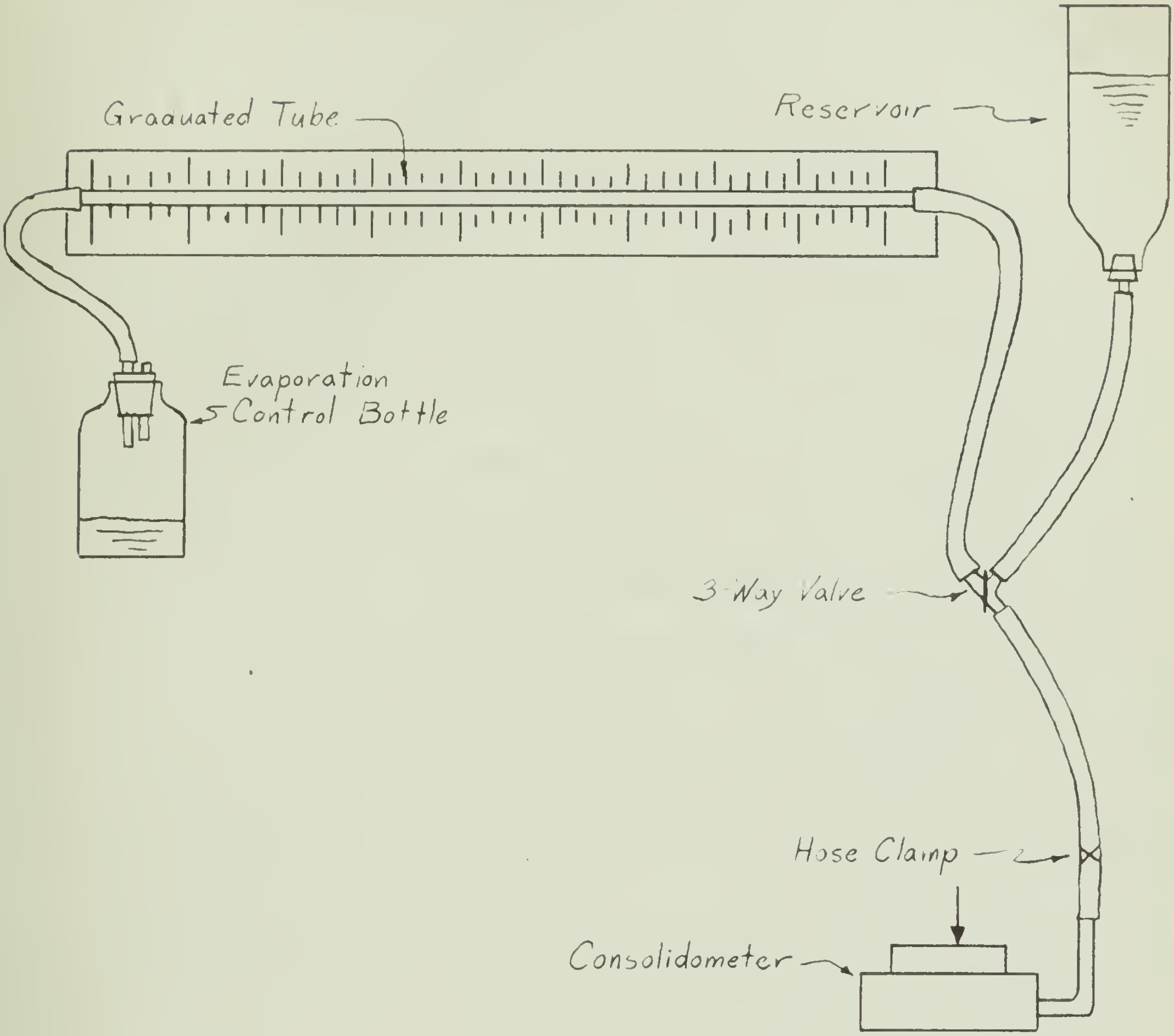
Permeability readings throughout all tests utilized a constant head permeameter as shown in Figure 8.



TIME-DEPENDENT LOADING DEVICE (Schematic)

Figure 7

CONSTANT HEAD PERMEAMETER



OPERATING PROCEDURE

1. Attach Hose To Consolidometer With Hose Clamp Attached And With 3-Way Valve Closed To Graduated Tube, Making Sure That No Air Bubbles Are Trapped In Consolidometer.
2. Open 3-Way Valve To Graduated Tube And Allow Water To Flow Into Evaporation Control Bottle Until All Air Bubbles Are Purged From System.
3. Close Three Way Valve To Reservoir, Open Hose Clamp, And Set Zero Reading On Graduated Tube.

Figure 8

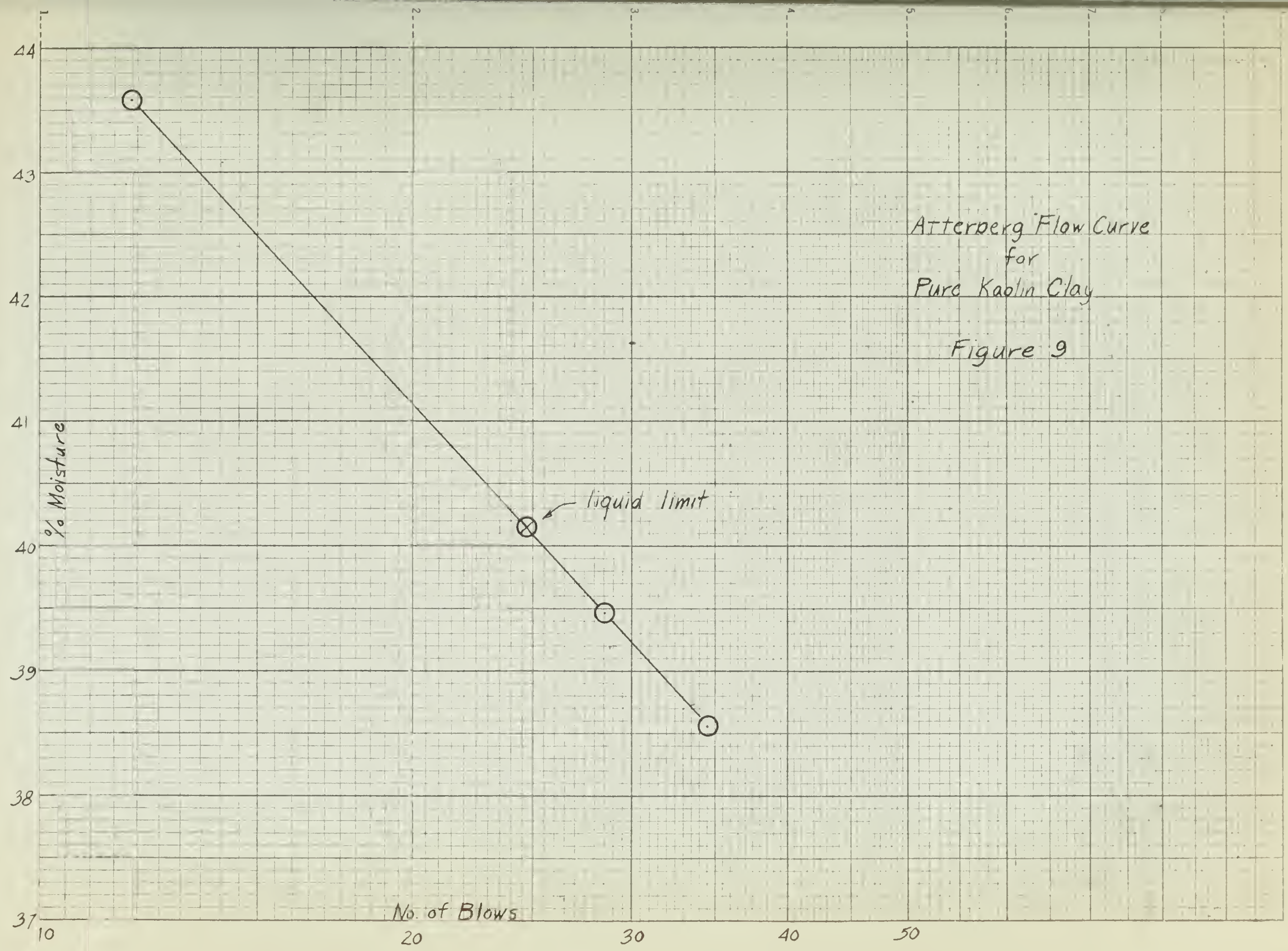
PART IV.

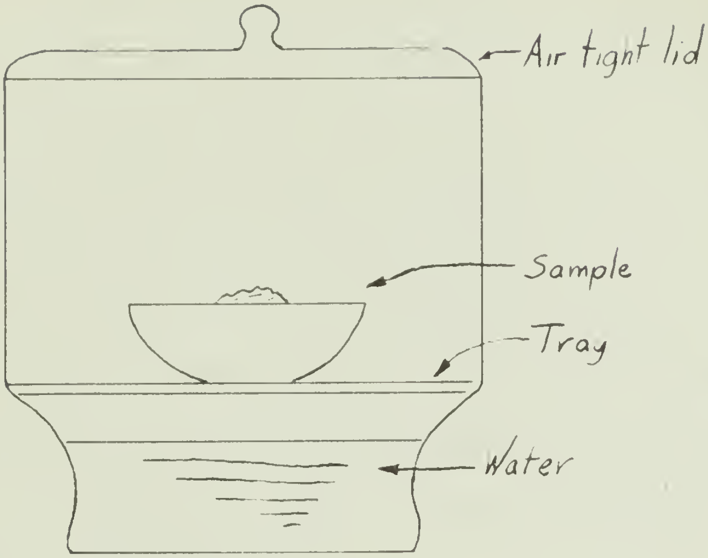
METHOD OF PROCEDURE

A. Preparation of Sample

Preparation of samples was at the liquid limit which was computed according to ASTM Standards. The flow curve from this determination is shown in Figure 9. This agreed favorably with the value determined by Marron (4), so only one value was computed. Mixing was accomplished by adding distilled water to 150 grams of dry kaolin and blending with a standard spatula. Enough water was added to bring the moisture content to approximately 3% above the liquid limit (44%). After blending was complete, the sample, in a porcelain evaporating dish, was placed in dessicator which had been converted to a humidifier by removing the dessicant and placing water in the bottom. This aging period lasted twelve hours and was meant to permit a more thorough saturation of the sample, thus more closely approximating a homobeneous material. The humidifier is shown in Figure 10.

The sample was placed in the consolidometer as set forth by Marron (4), but it was especially attempted to equalize for each sample preparation the periods utilized in removing entrapped air. Again, it was thought that a closer approach to homogeneity of all samples throughout the testing would be gained by standardization of the preparation procedure.


Atterberg Flow Curve
for
Pure Kaolin Clay
Figure 9
liquid limit
% Moisture
No. of Blows
44
43
42
41
40
39
38
37
10
20
30
40
50



Humidifier

Figure 10

Test #	Loading Rate $\frac{TSF}{HR}$	Final Load (TSF)
1	2.15	15.45
2	2.07	9.50
3	1.89	13.20
4	2.00	13.27
5	1.78	15.50
6	1.78	13.28
7	2.15	15.80
8	1.20	14.80
9	1.32	13.25
10	1.10	15.48
11	2.50	12.81
12	2.75	13.80
13	2.21	11.60

Continuous Loading Data

Table I

B. Static Loading Test

Three series of static loading tests were run. The first, the so-called "usual test", was run as a pilot study to establish procedures and to become acquainted with the equipment. Increments of loading were as follows (Tons per Square Foot): 0-1/4, 1/4-1/2, 1/2-1, 1-2, 2-4, 4-8.

The second test was labeled the small increment test and consisted of loadings as follows: 0-1/4, 1/4-1/2, 1/2-1, 1-1 1/2, 1 1/2-2, 2-2 1/2, 2 1/2-3, 3-3 1/2, 3 1/2-4, 4-4 1/2, 4 1/2-5, 5-6, 6-7, 7-8.

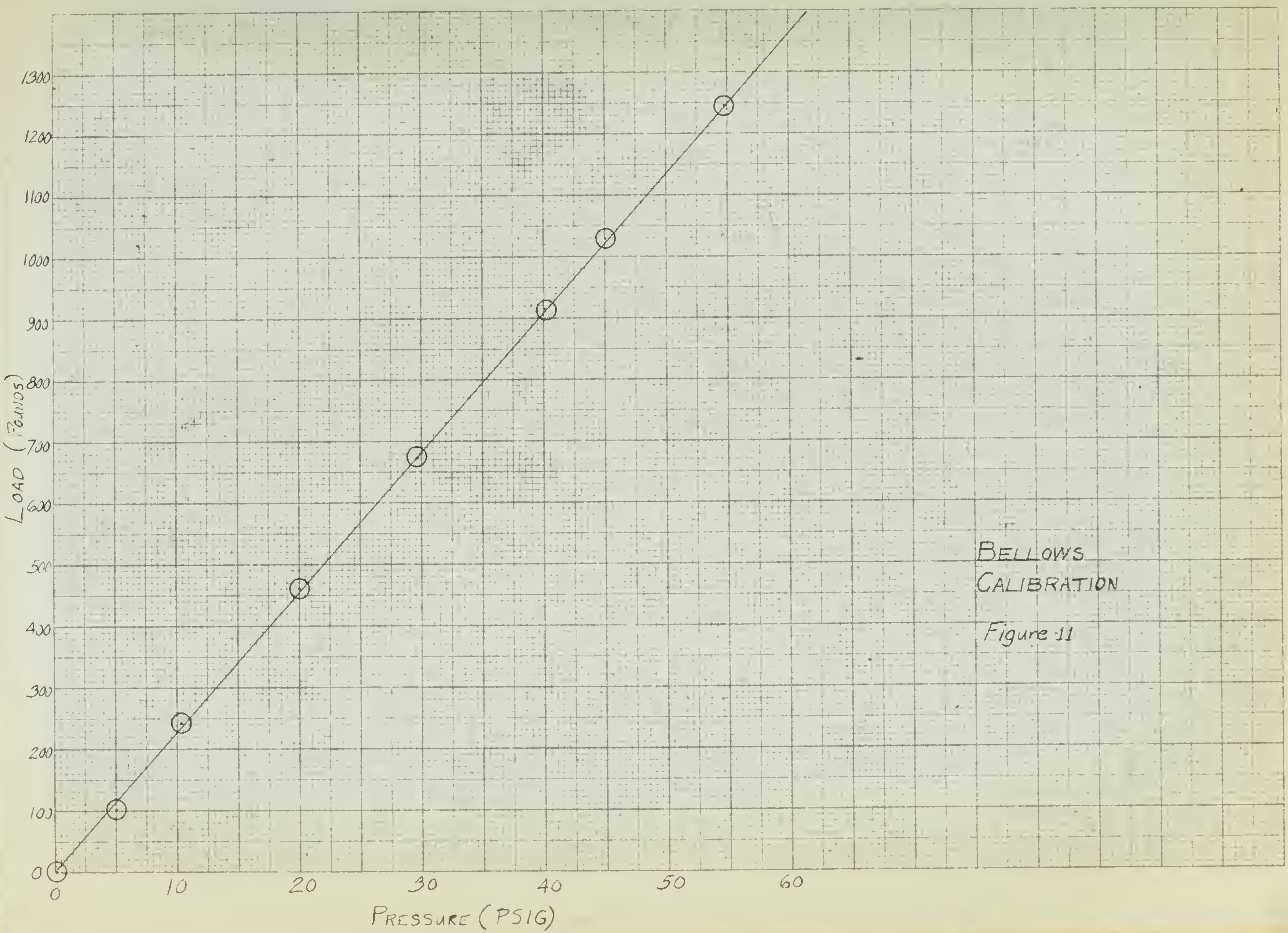
The third test was labeled the large increment test and consisted of loadings as follows: 0-1/2, 1/2-1, 1-2, 2-4, 4-8.

A sample data sheet is contained in Appendix I.

C. Time-Dependent Loading Test

A total of thirteen continuous loading tests were run. However, at the beginning of testing it was noted that the bellows had a slight permanent tilt to it. Upon application of load it became more canted until it no longer imposed an axial load upon the specimen. Therefore, a new bellows was procured. As a result, calibration became necessary. Calibration was simplified considerably from that mentioned by Marron (4) by use of a standard materials testing machine. Procedure was as follows: The bellows was placed in the machine so to prevent vertical expansion upon applying air pressure to the bellows. Air pressure was then gradually increased up to the maximum available in the local air system, and a plot was made of this air pressure versus the pressure exerted by the testing machine, read directly off the machine dial in pounds. This calibration agreed precisely with that of the former bellows. The calibration curve is shown in Figure 11. The spring constant was determined by attaching a spring scale to the bellows, exerting a vertical load while plotting the vertical expansion of the bellows versus the load in pounds read from the spring scale. This curve is shown in Figure 12.

The procedure for operating this equipment is set forth in Figure 6, and is supplemented by information in the Materials and Apparatus section of this paper.


BELLOWS
CALIBRATION
Figure 11
LOAD (POUNDS)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
PRESSURE (PSIG)
0
10
20
30
40
50
60

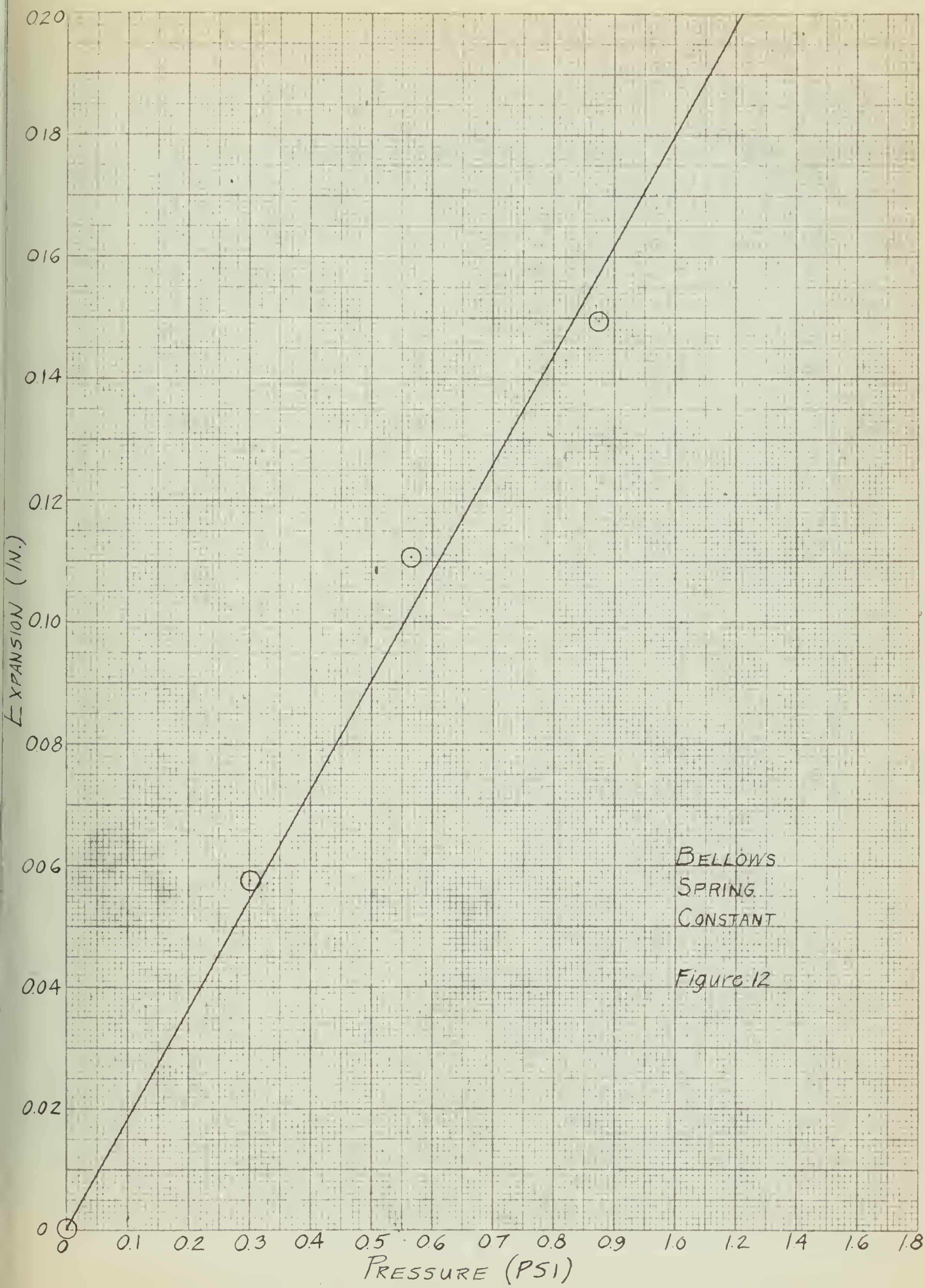

0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
EXPANSION (IN.)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.2
1.4
1.6
1.8
PRESSURE (PSI)
BELLOWS
SPRING
CONSTANT

Figure 12

The rates of loading, and final loads imposed are set forth in Table 1. Sample data sheets are included in Appendix II.

D. Permeability Measurements

Permeability readings were taken throughout the testing runs as far as practicable. A constant head permeameter as depicted in Figure 8 was used. The procedure for utilizing this permeameter is also included on Figure 8.

Since considerable head was utilized in this permeameter there was necessarily a delay before permeability readings could be taken. As set forth in Marron (4) sample uplift occurs. It will also be noted that readings were taken during the process of consolidation even though it was realized that values of K (coefficient of permeability) computed from these readings would be false. It was thought, however, that some relationship between the rate of loading and the variations of these computed values might become evident.

PART V.

RESULTS

Data from the three series of static tests and the twelve runs are presented graphically in Figures 13 through 20.

Consolidation readings were made directly, void ratio and porosity being computed from them. Permeability measurements were taken with the aid of a constant head manometer.

Figure 13 represents the standard "void ratio vs. logarighm of pressure" relationship. It can be seen that, with slight exception, the slopes of all the relatively straight lines are equal. In fact, for the fifteen test runs represented on this plot, the only factor that seems to govern the position of one curve relative to another is the initial void ratio. The values for void ratio at the commencement of these tests varied from approximately 1.000 to 1.400 and the values at the beginning of the plot varied from approximately 0.775 to 1.02. At the end of the plot the void ratio values varied from approximately .525 to .750, which fact indicates that little, if any, convergence or divergence of the curves occurs regardless of the rate of loading.

Figures 14 and 15 show the relationship of void ratio to time for the different loading rates. For static

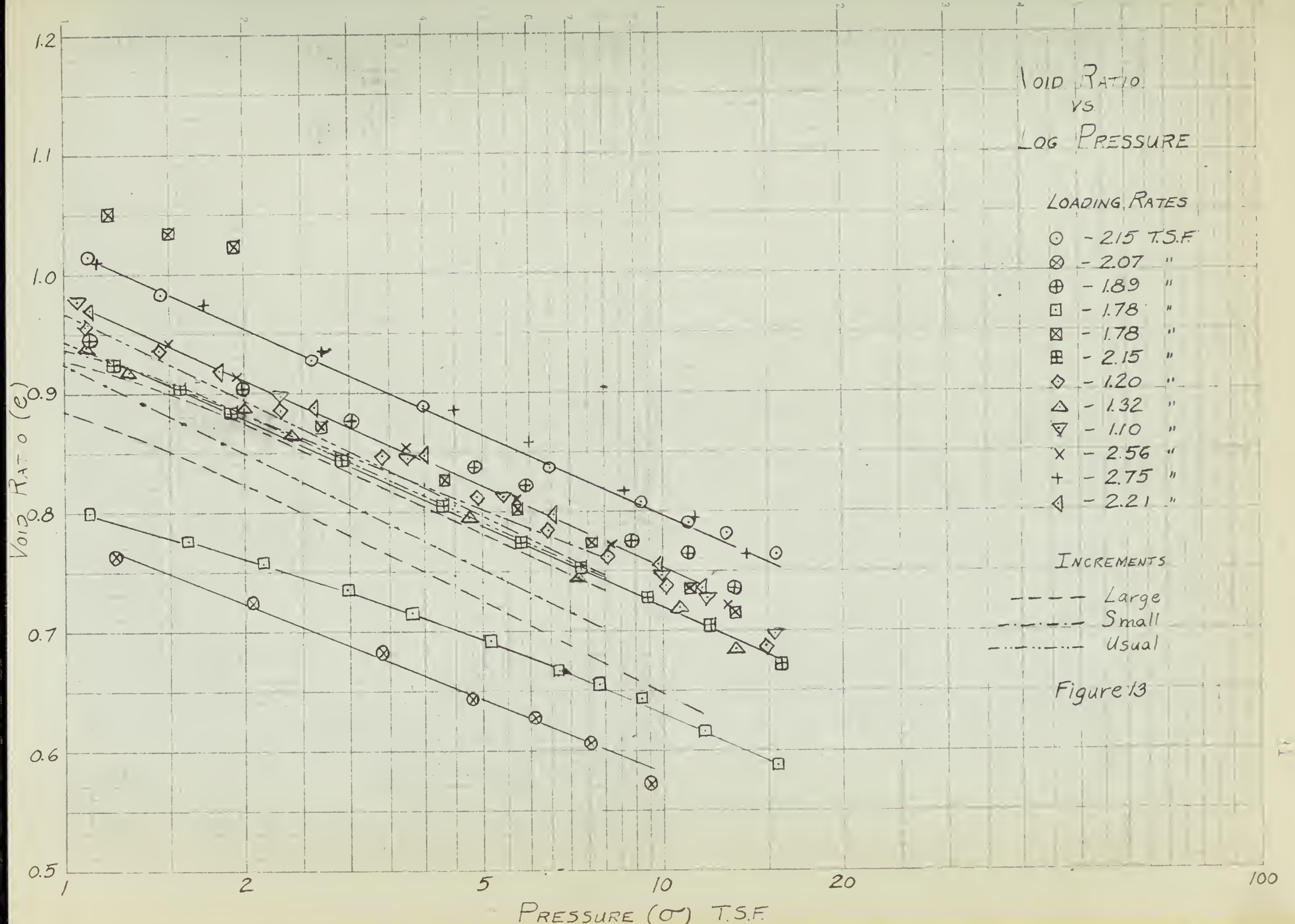
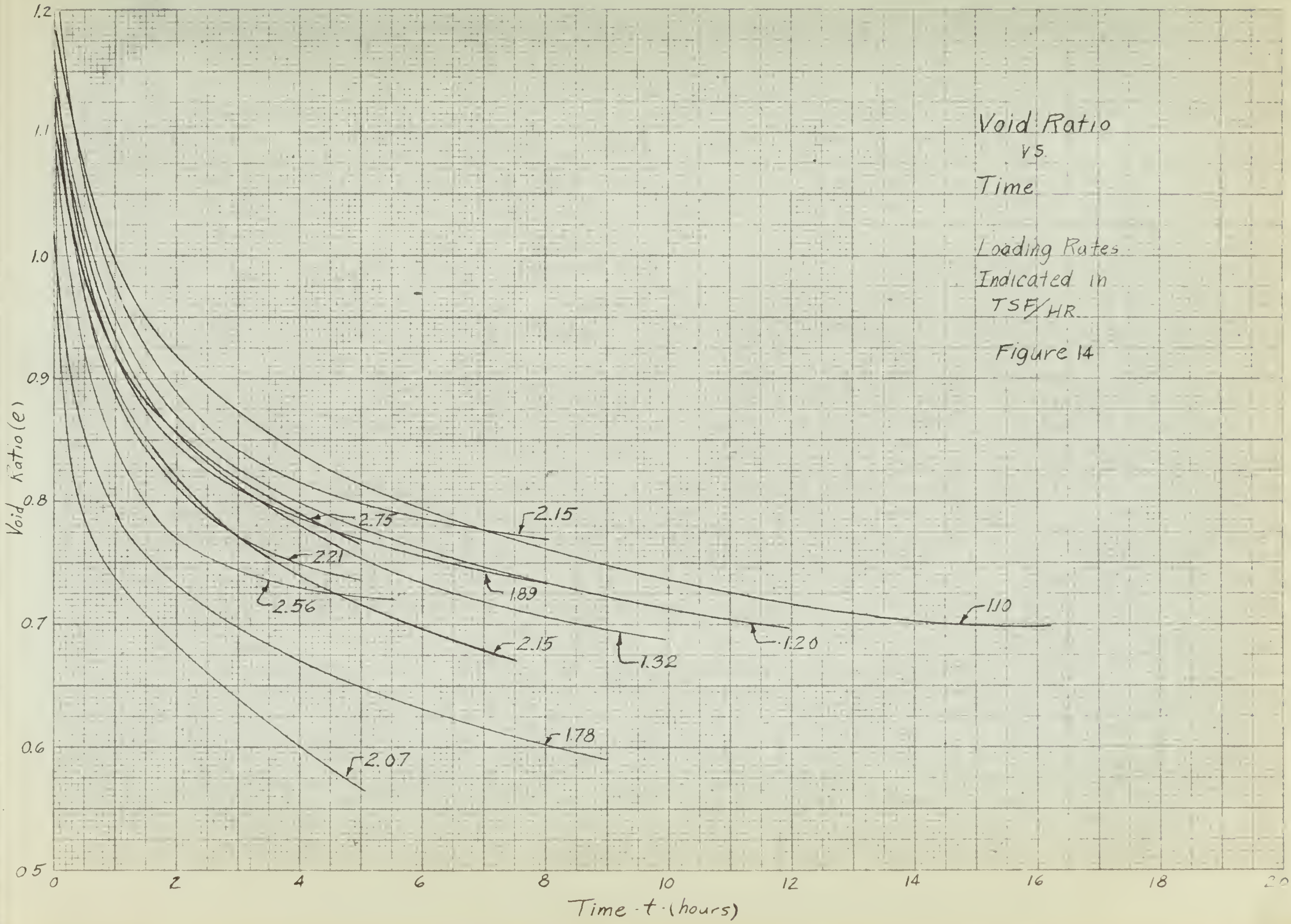
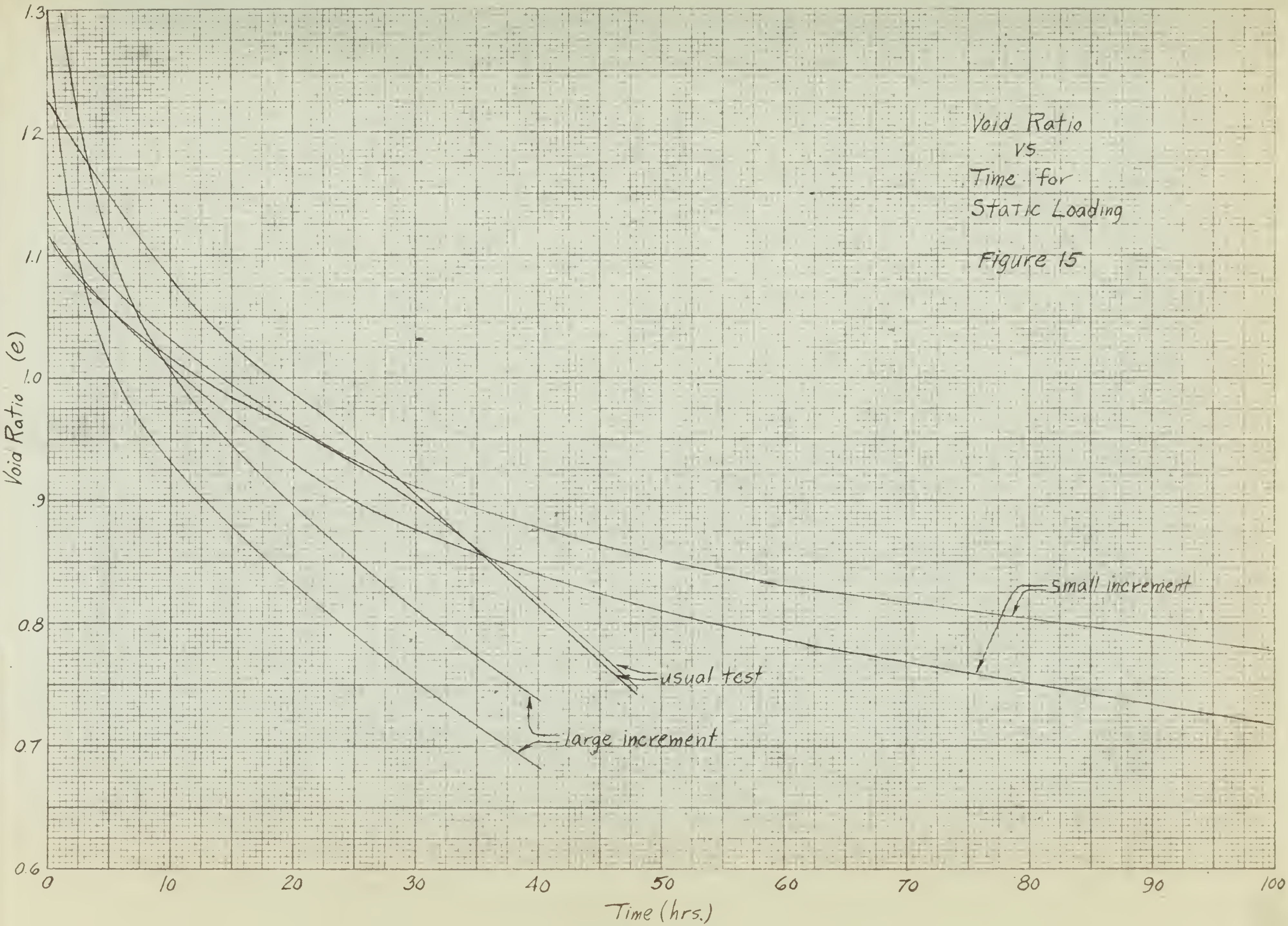

Void Ratio
vs
Log Pressure
Loading Rates
- 2.15 T.S.F
- 2.07 "
- 1.89 "
- 1.78 "
- 1.78 "
- 2.15 "
- 1.20 "
- 1.32 "
- 1.10 "
- 2.56 "
- 2.75 "
- 2.21 "
Increments
Large
Small
Usual
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
1
2
5
10
20
100
Void Ratio (e)
Pressure (σ) T.S.F

Figure 13


Void Ratio
vs
Time
Loading Rates
Indicated in
TSF/HR
Figure 14
Void Ratio (e)
Time · t · (hours)
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0
2
4
6
8
10
12
14
16
18
20
2.75
2.15
2.21
1.89
2.56
1.10
1.20
2.15
1.32
1.78
2.07

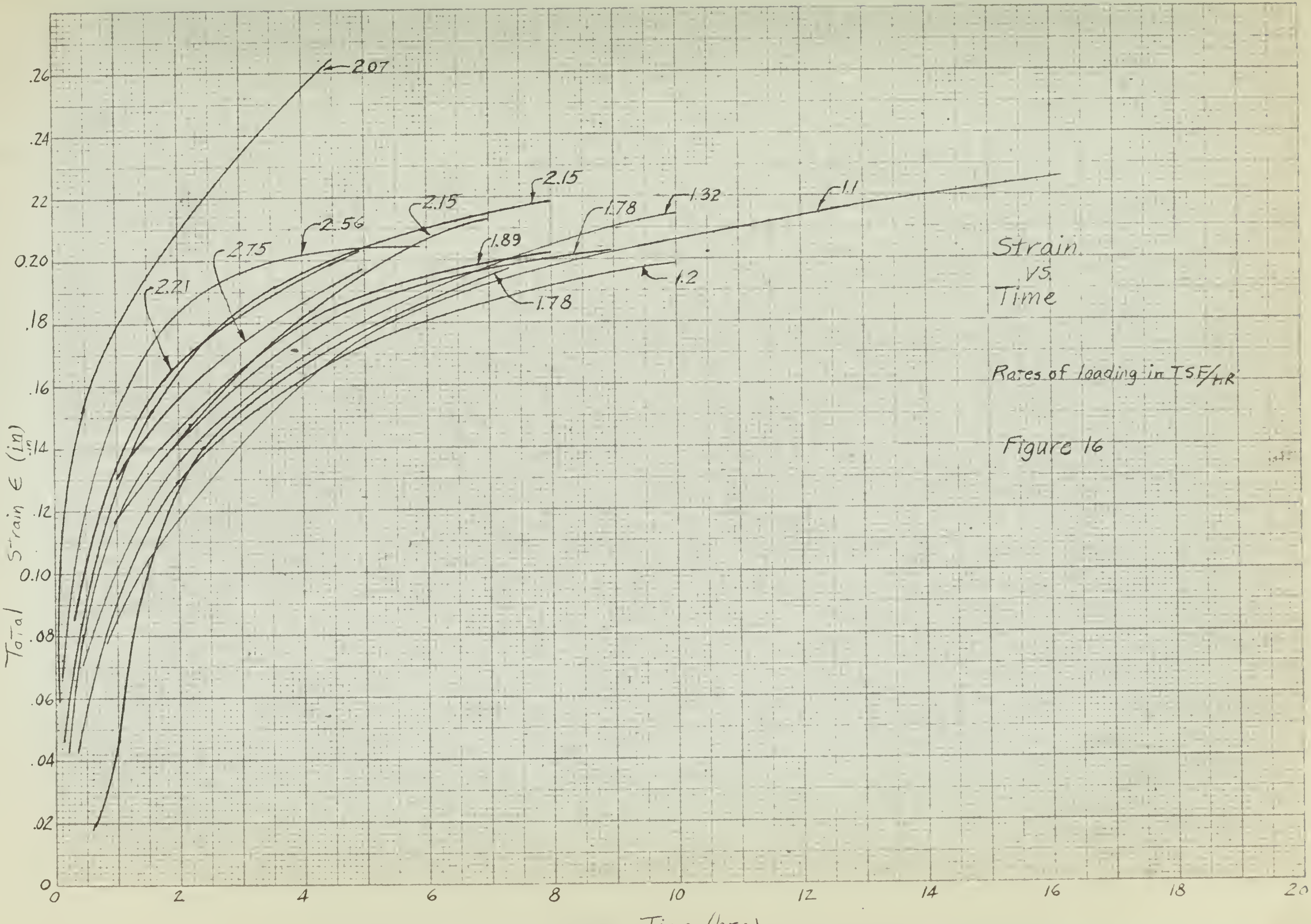

Void Ratio
vs
Time for
Static Loading
Figure 15
Small increment
usual test
large increment
Void Ratio (e)
Time (hrs.)
1.3
1.2
1.1
1.0
.9
0.8
0.7
0.6
0
10
20
30
40
50
60
70
80
90
100

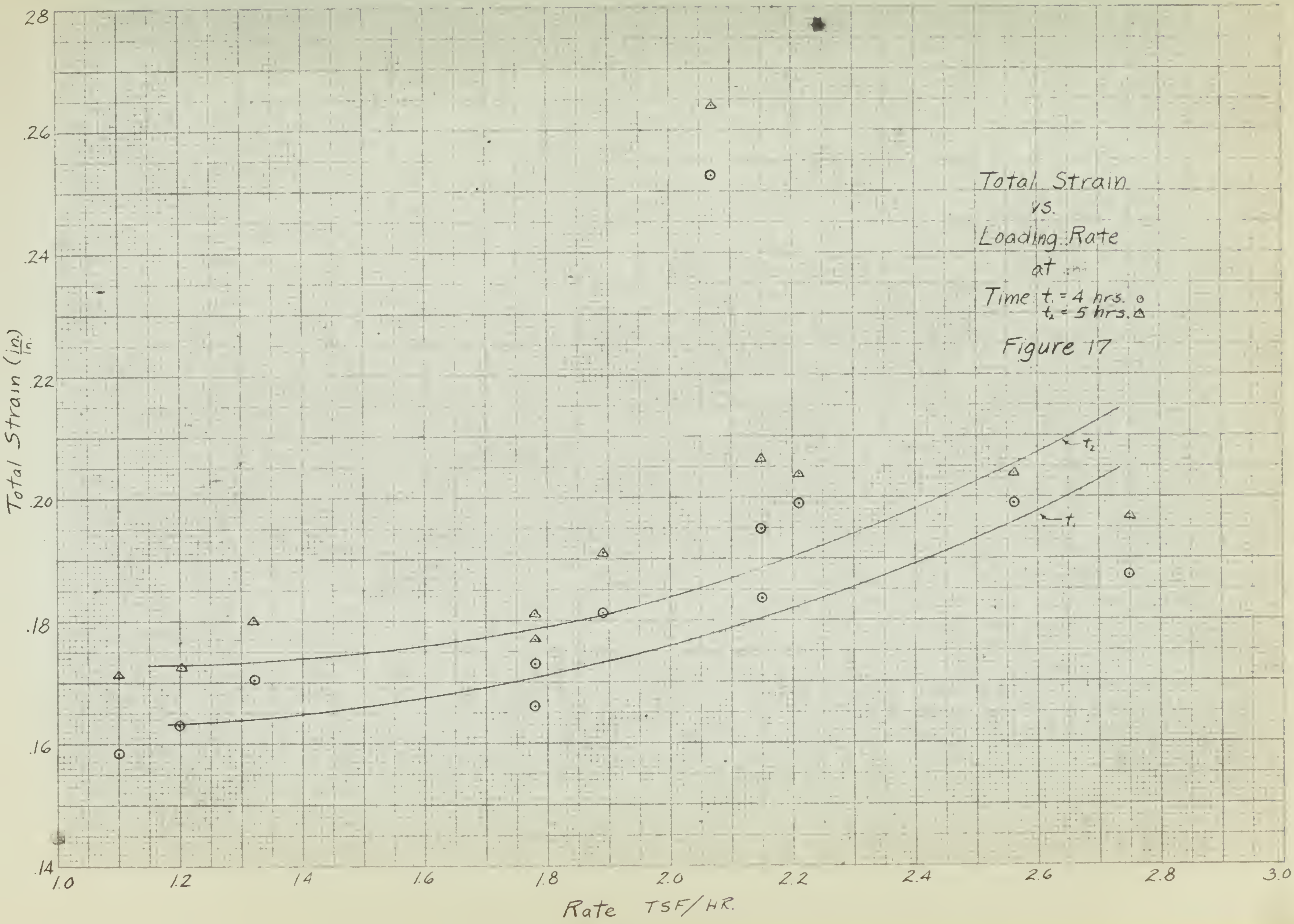
loadings it is seen that there is a definite trend toward smaller void ratio decrease with increase in load increment, although in each test the ultimate load was eight tons per square foot.

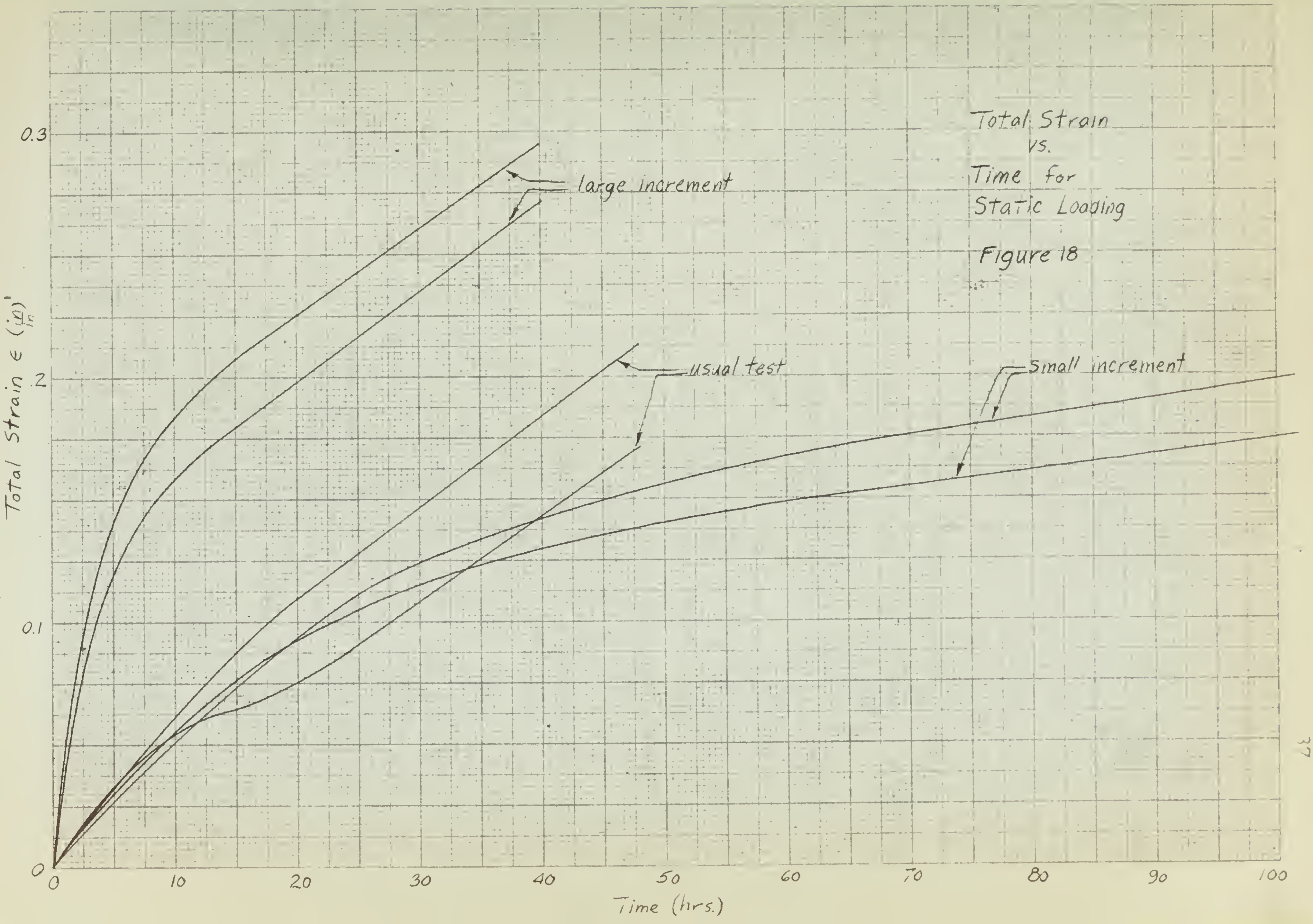
For the time-dependent (continuous-loading) tests, however, the results are not as conclusive. It is seen, though, that the more rapid loading rates are tending to approach an assymptcte more rapidly and at a smaller void ratio change than the less rapid loading rates.

Figures 16 and 18 depict the relationship of total strain with time for different loading conditions. As can be gathered from the void ratio plot (Figures 14 and 15), the total deformation is shown to be greater for more rapid rates of loading. This is again illustrated on the plot for the static test where considerably greater total strains were experienced for large incremental test runs than for small incremental tests. The so-called usual test, which was used as a pilot study, has increments of loading between those of the other two series; however, in spite of the fact that these usual tests were subject to more error since technique was not fully developed at that early stage of testing, the plot of total strain falls between the two extremes of small increment and large increment.

This effect is further illustrated by Figure 17 which is a plot of total strain versus rate-of-loading at a particular time during testing, in this case 4 hours.


Strain vs Time
Rates of loading in TSF/HR
2.07
2.15
2.15
2.56
2.75
2.21
1.89
1.78
1.32
1.1
1.2
1.78
.26
.24
22
0.20
.18
.16
.14
.12
0.10
.08
.06
.04
.02
0
0
2
4
6
8
10
12
14
16
18
20
Total Strain ∈ (in/in)
Time (hrs.)
Figure 16


Total Strain
vs.
Loading Rate
at
Time t₁ = 4 hrs. ⊙
t₂ = 5 hrs. △
Figure 17
t₂
t₁
Total Strain (in./in.)
.28
.26
.24
.22
.20
.18
.16
.14
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
Rate TSF/HR.



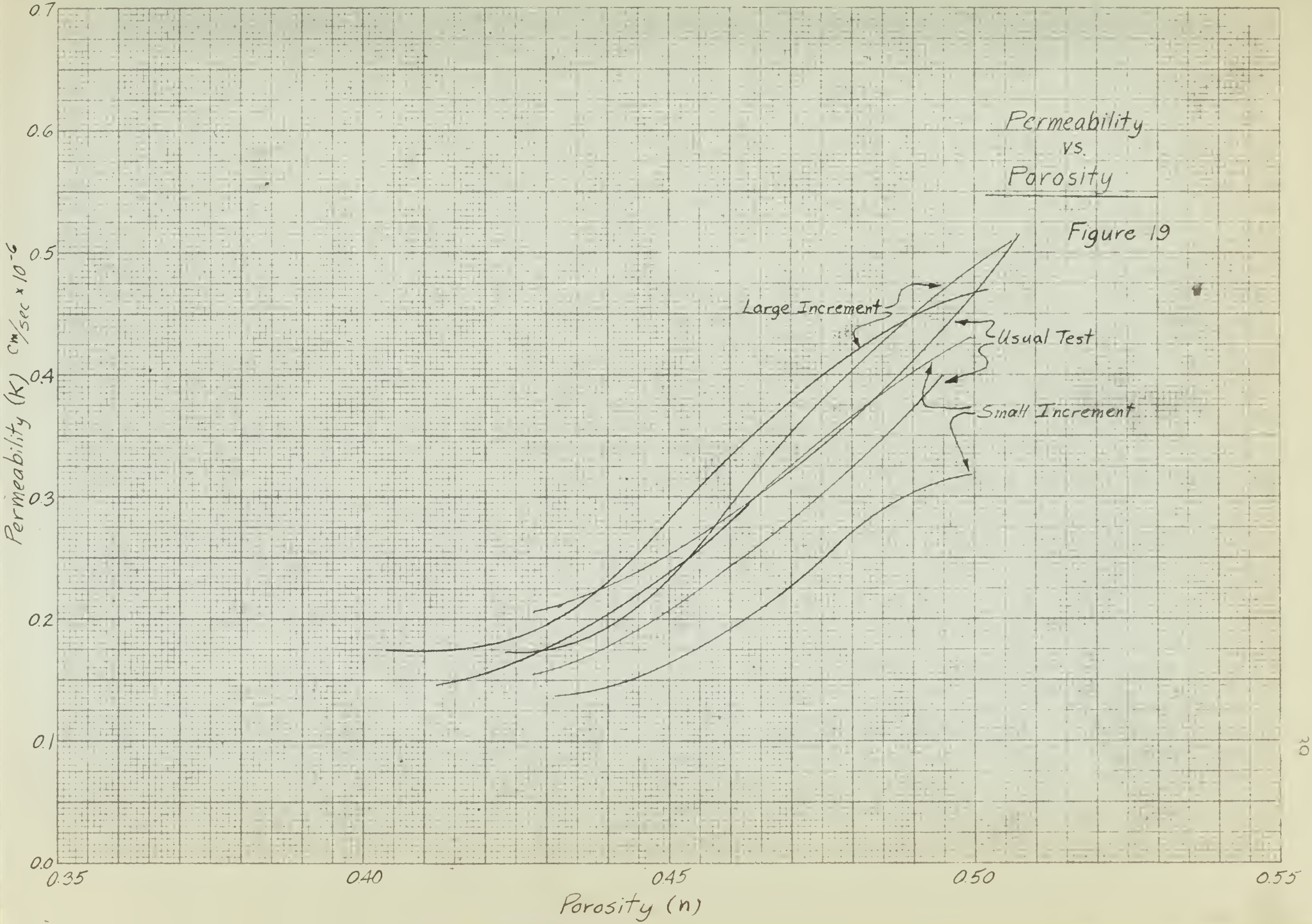
Total Strain vs. Time for Static Loading
Figure 18
large increment
usual test
Small increment
Total Strain ϵ (in/in)
0.3
.2
0.1
0
0
10
20
30
40
50
60
70
80
90
100
Time (hrs.)

Although there is some scattering of points, the plotted curve seems to indicate that total strain increases at an ever-increasing amount as rate of loading increases.

Figures 19 and 20 are graphical representations of permeability versus porosity for various loading conditions. Although a total of thirteen test runs were accomplished with the continuous loading device, no definite relationship between permeability and porosity could be discovered. Since the only true permeability value was the one measured at the conclusion of loading, only one value could be plotted for each run. No two values were the same, even when the same rate of loading was applied. It must be noted, however, that the total spread between permeability values was from .083 cm/sec x 10^{-6} to 0.12 cm/sec x 10^{-6} while the loading rates varied from 1.1 TSF/HR to 2.75 TSF/HR and the final load values varied from 11.60 TSF to 15.80 TSF.

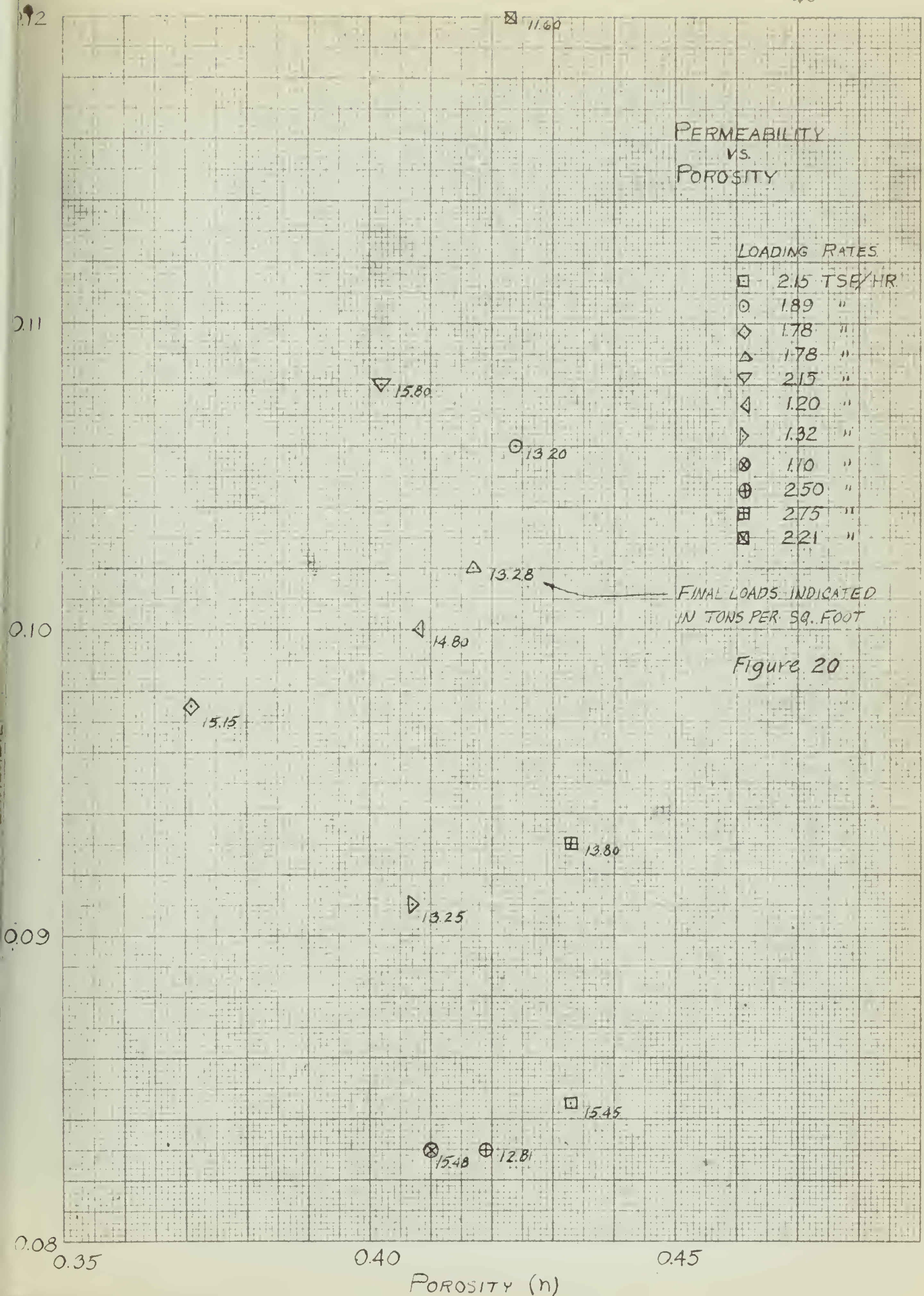
For the static tests, however, a continuous curve could be plotted, since values for permeability were measured at the equilibrium point after every load increment. The curves plotted essentially parallel, and the permeability values for the large increment test runs were consistently larger than the values for the small increment test runs. Again, the usual test values lay between these two extremes.

A plot of permeability-versus-time for these same static tests (Figure 21) seems to substantiate the above results since there is a tendency for permeability to be



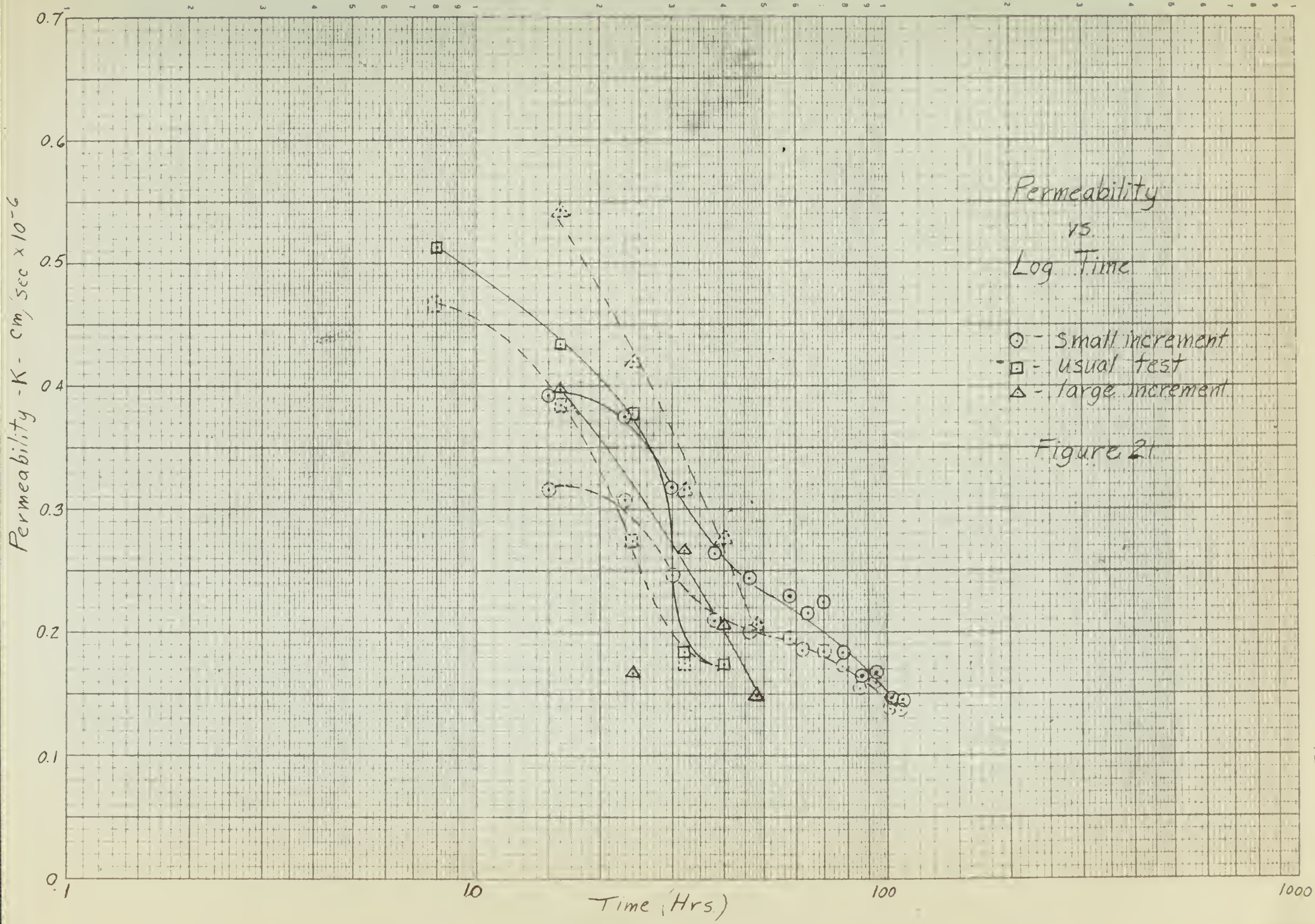
Permeability vs. Porosity

Figure 19



0.12
0.11
0.10
0.09
0.08
0.35
0.40
0.45
POROSITY (n)
PERMEABILITY
VS.
POROSITY
LOADING RATES
2.15 TSF/HR
1.89 "
1.78 "
1.78 "
2.15 "
1.20 "
1.32 "
1.10 "
2.50 "
2.75 "
2.21 "
FINAL LOADS INDICATED
IN TONS PER SQ. FOOT
11.60
15.80
13.20
13.28
14.80
15.15
13.80
13.25
15.45
15.48
12.81

Figure 20


Permeability
vs
Log Time
⊙ - Small increment
⊡ - usual test
△ - large increment
Figure 21
Permeability -K- cm/sec x 10^-6
Time (Hrs.)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.
1
10
100
1000

greater for the large incremental test than for the small incremental test with values for the usual test falling between these two extremes.

PART VI.

DISCUSSION

A. Static Tests

Six runs, two each of large increment, small increment and usual increment, were conducted in the series of static tests. Although these tests constituted a slight change from the standard consolidation tests, the course of testing was nonetheless followed at the suggestion of Marron (4).

The results of the tests are both interesting and applicable. The fact that total strain and resultant void ratio decrease is larger for a large incremental load application could have far-reaching effects in construction. Most foundation designs are based on an allowable differential settlement. The fact that large increments of loading cause greater total consolidation than small increments of loading, even though the final total loads are equal, leads to the possibility of greater differential settlement under these large incremental conditions.

This phenomenon can probably be explained by hypothesizing that the smaller load increments cause less disturbance to the structure of the clay and concurrently allow more opportunity for the natural structure to develop than do the large increments. Therefore, it is conceivable that less total strain would take place if the structural

strength had built up to a greater extend under the smaller increments.

There are limitations to this concept, however, and far from the least of these is the fact that the study dealt with an ideal material, pure kaolinite. Of course, for the sake of study homogeneity simplifies the interpretation of results, but whether any field conditions approach this is another question entirely.

Figure 19 illustrates that the permeability is greater at time t and at porosity n for large increment than for small increment tests. It would seem, from the foregoing discussion, that the smaller increments would produce the large permeabilities since the total strain and void ratio change is less. Thus a question and a conflict arise.

It is readily seen that this line of testing presents interesting possibilities and certainly merits further research.

B. Time-Dependent Loading Tests

Thirteen so-called continuous loading tests were conducted as a refinement of the standard static testing. Previous work by Marron (4) had been hampered by the lack of a dependent variable loading device. The electric motor--gear train--belt and pulley arrangement was a great improvement over his bubbler but is not the final answer. The valve stem of the air pressure regulator valve became extremely difficult to turn as the pressure was increased. Therefore, at relatively high pressures (40 psi) slippage of the belt on the pulleys occurred. As a result, pure time-dependent loading was not always obtained and the final pressures were not always as large as desired. A gear drive instead of the belt and pulley drive would solve this problem. Nevertheless, the tests as a whole proved quite satisfactory.

These tests seem to verify the results of the static tests in that the more rapid loading rates produced the greatest total strains and void ratio changes.

No such verification can be gathered from the plot of permeability versus porosity (Figure 19). The scattering of values is too random to permit the formulation of a general relationship. Perhaps if more time had been allowed to elapse after the discontinuation of additional loading before the reading of permeabilities, a relationship could be developed. Since there is such a small spread relatively, however, (from .083 to .12 cm/sec x 10^{-6}) a general

statement can be made. From the results of this series of tests there is relatively little effect upon permeability of rate of time-dependent loading.

C. General

The results of these tests, although to some extent conclusive, bring to the author's mind many ideas for furthering the study.

A direct result of the time limitation is the factor of human error. In a research problem such as this the innumerable variables present in the raw material, in this case soil, are further compounded by the variation in technique of testing. Even though the soil samples are prepared with great diligence, no two samples are exactly alike. This alone accounts, more than likely, for most of the error in the test results. The plot of void ratio versus log of pressure (Figure 13) is a prime example. If the samples had all been prepared equally, the plot would have been one line.

Of course, the human error decreases as technique is improved and experience is gained.

If any further testing is contemplated, the following suggestions are offered:

(1) The loading block of the consolidometer should be attached to the loading beam of the loading apparatus. This will eliminate much of the initial disturbance and early false readings caused by the relatively heavy weight of the block resting on the sample and yet not being included in the measured applied pressure.

(2) A gear train should be fabricated to replace the belt and pulley drive. This will insure constant time-dependent loading.

(3) The testing program should include series of tests at various rates of loading. At each rate of loading tests should be run from 0-1 TSF, 0-2 TSF, 0-3 TSF, up to 0-16 TSF. When each of these predetermined loads are reached, permeability readings should be taken after a predetermined waiting period to allow equilibrium to take place.

(4) An automatic recording device (i.e., photographic) should be utilized especially during the initial half hour of testing. The process takes place too rapidly to permit accurate readings by eye. This record should include the manometer readings during the initial stages when water is forced back into the tube.

PART VII.

CONCLUSIONS

1. The utilization of an electric motor--gear train--belt and pulley device in conjunction with a Conbel loading apparatus is feasible and provides very good control in consolidation experiments.
2. There is a relationship between rate of loading and total consolidation. The larger the increment or the more rapid the rate of loading, the greater the total consolidation and the greater the resultant decrease in void ratio.
3. The fact that increment of loading does affect the permeability--porosity relationship is an indication that rate of loading does play a part. Although this same plot for the various rates of continuous loadings was inconclusive, certainly further study along this line is warranted.
4. The assumptions by Schiffman (5) that permeability is not constant under varying loading conditions during the consolidation process are valid.

PART VIII.

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APPENDIX A

Sample Raw Data

Static Loading Tests

Large Increment Static Loading 23 Mar '59

	Time	ΔT	Press TSF	Dial	Dial in.	Ht. in.	Vol. in^3	V_s	$e=\frac{V}{V_s}-1$	$n=\frac{e}{1+e}$	Perm Gage	ΔQ cc	K $\frac{cm}{sec}\times10^{-6}$
	0906	0 s	0	1150	.0350	1.0038	4.925	2.137	1.305	.566			
W = 43%		10		5130	.1130	.9258	4.542		1.125	.529			
		20		5180	.1180	.9208	4.517		1.114	.527			
		30		6020	.1220	.9168	4.498		1.105	.525			
		40		6050	.1250	.9138	4.48[illegible]		1.098	.523			
		50		6070	.1270	.9118	4.473		1.093	.522			
	0907	1 m		6090	.1290	.9098	4.463		1.088	.521			
		1½		6145	.1345	.9043	4.436		1.076	.518			
	0908	2		6185	.1385	.9003	4.417		1.067	.516			
	0909	3		7050	.1450	.8938	4.385		1.052	.513			
	0910	4		7100	.1500	.8888	4.360		1.040	.510			
	0911	5		7130	.1530	.8858	4.346		1.034	.508			
	0916	10		8048	.1648	.8840	4.337		1.029	.507			
	0926	20		8137	.1737	.8829	4.332		1.027	.506			
	0936	30		8190	.1790	.8776	4.306		1.015	.504			
	1006	60		9033	.1833	.8733	4.284		1.005	.501			
	1106	120		9053	.1853	.8713	4.275		1.000	.500			
	1306	240		9069	.1869	.8697	4.267		.997	.499			
	1645	480		9077	.1877	.8689	4.263		.995	.498			
	1647										0.00		
	1657										0.40	0.40	.416
	1707										0.90	0.50	.520
	1717		½								1.35	0.45	.468

Large Increment Static Test — 24 Mar. '59

	Time	ΔT	Press TSF	Dial	Dial in.	Ht. in.	Vol. in.³	V_s	$e=\frac{V}{V_s}-1$	$n=\frac{e}{1+e}$	Perm Gage	ΔQ cc	K $\frac{cm}{sec}\times10^{-6}$
	0859	0 sec	1/2	9093	.1893	.8495	4.168	2.137	.950	.487	.42		
		10	↓	9172	.1972	.8416	4.129	↓	.932	.482			
		20		9195	.1995	.8393	4.118		.927	.481	.10		
		30		10020	.2020	.8368	4.105		.921	.479			
		40		10030	.2030	.8358	4.100		.919	.478			
		50		10039	.2039	.8349	4.096		.917	.477			
	0900	1 min.		10048	.2048	.8340	4.092		.914	.476	0.0		
		1 1/2		10070	.2070	.8318	4.081		.910	.476	0.0		
	0901	2		10082	.2082	.8306	4.075		.907	.475			
	0902	3		10095	.2095	.8299	4.071		.905	.474			
	0903	4		10102	.2102	.8292	4.068		.904	.474			
	0904	5		10106	.2106	.8288	4.066		.903	.474			
	0909	10		10115	.2115	.8279	4.062		.901	.474	.17	.37	368
	0919	20		10122	.2122	.8272	4.058		.899	.473	.54	.41	-06
	0929	30		10126	.2126	.8268	4.056		.898	.473	.95	1.11	.368
	0959	60		10132	.2132	.8262	4.055		.898	.473	2.06	2.22	.350
	1059	120		10138	.2138	.8256	4.050		.895	.472	4.28	4.54	.370
Refilled to 0.1 c.c.	1259	240	↓	10145	.2145	.8248	4.046		.893	.472	8.82	7.43	.202
	1622		1	10150	.2150	.8243	4.044		.892	.471	7.53	.39	.385
	1632										7.92	.38	.385
	1642										8.30	.39	.385
	1652										8.69		

Large Increment Static Test

25 Mar. '59

	Time	ΔT	Press TSF	Dial	Dial in	Ht. in.	Vol. in.^{3}	V_s	$e=\frac{V}{V_s}-1$	$n=\frac{e}{1+e}$	Perm Gage	ΔQ cc	K $\frac{cm}{sec}\cdot 10^{-6}$
	0836	0 s	1	10181	.2181	.8207	4.026	2.137	.884	.469	2.38		
		10		11070	.2270	.8118	3.983		.864	.464			
		20		11109	.2309	.8079	3.963		.854	.461			
		30		11134	.2334	.8054	3.951		.849	.459			
		40		11153	.2353	.8035	3.942		.845	.458	-		
		50		11166	.2366	.8022	3.936		.842	.457			
	0837	1 m.		11176	.2376	.8012	3.931		.839	.456	1.72		
		1½		11196	.2396	.7992	3.921		.835	.455	1.69		
	0838	2		12005	.2405	.7983	3.916		.832	.454	1.68		
	0839	3		12014	.2414	.7974	3.912		.831	.454			
	0840	4		12018	.2418	.7972	3.911		.830	.453	1.70	.02	.191
	0841	5		12022	.2422	.7968	3.909		.829	.452	1.72	.02	.191
	0846	10		12028	.2428	.7962	3.906		.828	.452	1.83	~~.02~~ .11	.210
	0856	20		12034	.2434	.7956	3.903		.826	.452	2.10	.11	.258
	0906	30		12038	.2438	.7952	3.901		.825	.452	2.36	.26	.251
	0936	60		12045	.2445	.7949	3.900		.825	.452	3.19	.83	.264
	1036	120		12050	.2450	.7944	3.897		.824	.452	4.75	1.56	.247
Refilled to 0.2 cc.	1236	240		12055	.2455	.7939	3.895		.824	.452	8.25	3.50	.277
	1545		2	12063	.2463	.7931	3.891		.821	.451	5.35	5.15	.159
	1555										5.75	.40	.274
	1605										6.15	.40	.274

Large Increment Static Test

26 Mar '59

	Time	ΔT	Press TSF	Dial	Dial in	Ht in.	Vol. in.^{3}	V_s	$e=\frac{V}{V_s}-1$	$n=\frac{e}{1+e}$	Perm. Gage	ΔQ cc	K $\frac{cm}{sec}\times10^{-6}$
	0808	0 sec	2	12087	.2487	.7901	3.876	2.137	.814	.449	1.31		
		10		13000	.2600	.7788	3.821		.788	.441	.95		
		20		13041	.2641	.7747	3.807		.781	.439	.86		
		30		13067	.2667	.7721	3.788		.773	.436	.78		
		40		13083	.2683	.7705	3.780		.769	.435	.73		
		50		13094	.2694	.7694	3.775		.766	.434	.71		
	0809	1 min.		13101	.2701	.7687	3.771		.765	.433	.69		
		1½		13113	.2713	.7675	3.765		.762	.432	.67		
	0810	2		13117	.2717	.7671	3.763		.761	.432	.65		
	0811	3		13123	.2723	.7666	3.761		.760	.432	.67	.02	.184
	0812	4		13126	.2726	.7663	3.759		.760	.432	.69	.02	.184
	0813	5		13128	.2728	.7661	3.758		.759	.432	.70	.01	.092
	0818	10		13135	.2735	.7654	3.755		.758	.432	.80	.10	.184
	0828	20		13140	.2740	.7649	3.753		.756	.431	1.00	.20	.183
	0838	30		13144	.2744	.7645	3.751		.754	.431	1.25	.25	.229
	0908	60		13149	.2749	.7640	3.748		.754	.431	1.90	.65	.198
	1008	120		13154	.2754	.7635	3.746		.753	.430	3.20	1.30	.198
	1208	240		13160	.2760	.7629	3.743		.752	.430	5.90	2.70	.206
Refilled to 0.4 cc.	1320									.430	7.60	1.70	.216
	1500		4	13166	.2766	.7623	3.740		.750	.429	2.55	2.15	.123
	1510										2.74	.19	.174
	1520									.429	2.94	.20	.175

Large Increment Static Test											27 Mar. '59		
	Time	ΔT	Press TSF	Dial	Dial in.	Ht in.	Vol. in^3	V_s	$e=\frac{V}{V_s}-1$	$n=\frac{e}{1+e}$	Perm Gage	ΔQ cc	K $\frac{cm}{sec}\times10^{-6}$
	1010	0 sec	4	13187	.2787	.7601	3.729	2.137	.745	.427	3.95		
		10		14125	.2925	7463	3.661		.713	.416			
		20		14165	.2965	.7423	3.642		.704	.413			
		30		14190	.2990	7398	3.629		.698	.411	3.30		
		40		15000	.3000	7388	3.625		696	.410			
		50		15009	.3009	7379	3.620		.694	.409			
	1011	1 min.		15013	.3013	7375	3.618		.693	.409	3.23		
		1½		15020	.3020	7368	3.615		692	.409	3.22		
	1012	2		15025	.3025	7363	3.612		.691	.408	3.22		
	1013	3		15029	.3029	7359	3.610		.689	.408	3.23	.01	.880
	1014	4		15032	.3032	7355	3.608		.688	.407	3.24	.01	.880
	1015	5		15034	.3034	.7353	3.607		.688	.407	3.25	01	880
	1020	10		15040	.3040	.7347	3.604		.686	.407	3.32	.07	.123
	1030	20		15045	.3045	.7342	3.602		.685	.406	3.48	.16	.141
	1040	30		15049	.3049	.7338	3.600		.685	.406	3.64	.16	.141
	1110	60		15054	.3054	.7333	3.598		.684	.406	4.17	.53	.155
	1210	120		15060	.3060	.7327	3.595		683	.406	5.25	1.08	.158
Refilled to 0.00	1410	240		15065	.3065	7322	3.592		.681	.405	7.30	2.05	.151
Final.	1645		8	15070	.3070	.7317	3.590		.680	.405	2.50	2.50	.142
	1655										2.70	.20	.175
Can # 55 : 13.1532	1705										2.90	.20	.175
+ Wet : 135.4617													
+ Dry : 105.2329													
W = 32.8 %													
Vol. =													

SAMPLE CALCULATIONS

$Q = KIA$

$K = Q/IA = \Delta Q \div (t \times \frac{H}{L} \times A) = \frac{\Delta Q \times L}{t \times H \times A}$

ΔQ = flow of water (c.c) during time t

t = time (seconds)

L = average length of sample over time t (in.)

H = head of permeameter (116.6 cm)

A = area of sample (4.906 in^2)

K = Coefficient of permeability (cm./sec. $\times 10^{-6}$)

$$K = \frac{\Delta Q}{t} \times \frac{L \cdot 2.54}{116.6 \cdot 4.906 \cdot (2.54)^2} = .000688 \times \frac{\Delta Q \cdot L}{t}$$

$$= .688 \times 10^{-3} \times \frac{\Delta Q \cdot L}{t} \quad \text{cm./sec.}$$

APPENDIX B

Sample Raw Data

Time-Dependent Loading Tests

[illegible]

[illegible]

Continuous Loading Test #1

16 Feb '59

Rate: 2.15 TSF/HR

Initial Meas.

Can #66
Tare: 13.0658
+Wet: 23.9983
+Dry: 24.2391
W = 42.7%

Final Meas

Can #44
Tare: 9.7275
+Wet 133.7110
+Dry . 103.8942
W = 31.7%
Vol. 3.945 in³

Bellows Canted To One Side

Time	Press. PSI	(−) Corr.	Press TSF	Dial	Dial in.	Hr in.	Vol. in.³	V_s	$C=\frac{V}{V_s}-1$	$n=\frac{e}{1+e}$	Perm Gage	ΔQ cc	K $\frac{cm}{sec}\times10^{-6}$
0845	0	0	0	15184	3184	.0065	4.938	2.186	1.259	557	0.5		
0854	0.5	0	.10	15100	.3100	9981	4.897		1.2[illegible]	554			
0856	0.7	.1	.13	14180	.2980	.9861	4.838		1.213	548			
0900	1.0	2	.15	13180	.2780	.9661	4.743		1.168	.539			
0908	1.8	.3	.45	13084	.2684	.9565	4.693		1.147	.534			
0918	3.0	.5	.80	11050	.2250	.9131	4.480		1.049	.512			
0921	3.3	.5	.90	10170	.2170	.9051	4.443		1.031	508			
0930	4.0	.5	1.10	10100	.2100	.8981	4.406		1.016	.504			
0938	4.8	.6	1.33	1003	.2003	.8884	4.358		.994	.498			
0942	5.2	.6	1.45	9153	.1953	.8834	4.334		.983	.496	~~0.5~~		
0948	5.8	.7	1.62	9115	.1915	.8796	4.315		.974	.493			
1000	6.3	.8	1.75	9008	.1808	.8689	4.263		.950	.491			
1015	9.0	.8	2.63	8110	.1710	.8591	4.215		.928	.48	~~.55~~		
1025	9.9	.8	2.82	8060	.1660	.8541	4.193		.917	.478			
1035	10.5	.9	3.00	8033	.1633	.8514	4.177		.911	.477	3.0	.0	
1042	11.9	.9	3.62	7181	.1581	.8462	4.151		.899	.473	2.9		
1052	13.1	.9	4.00	[illegible]	.1540	.8421	4.130		889	.471	2.85		
1100	14.0	1.0	4.30	7114	.1514	.8395	4.119		.884	.469	2.90	.08	.035
1122	16.6	1.0	5.12	7031	.1431	.8312	4.078		866	.464	2.88	.12	.041
1150	19.7	1.0	6.20	6152	.1352	.8233	4.026		.842	.457	3.00	.07	066
1200	20.6	1.0	6.50	6130	.1330	.8211	4.015		.837	.456	3.07	.08	035
1215	22.4	1.0	7.10	6094	.1294	8175	4.011		.835	.455	3.15	.12	.041
1234	24.4	1.1	7.70	6053	1253	8134	3.991		.826	.452	3.27	.08	.066
1251	26.4	1.1	8.40	6020	.1220	.8101	3.974		.818	.450	3.35	.10	.050
1310	29.0	1.1	9.25	5170	.1170	.8051	3.950		807	.447	3.45	–	
1330	31.0	1.1	9.93	5154	.1154	.8035	3.942		803	.445	3.45	.15	.82
1345	32.6	1.2	10.40	5122	.1122	.8003	3.926		.796	.443	3.60	.14	.024
1400	34.5	1.2	11.05	5090	.1096	.7971	3.914		.790	.44	3.64		
1505	35.4	1.2	11.33	5096	.1096	.7977	3.914		.790	.441	3.60		
1520	37.0	1.2	11.30	5081	.1081	.7962	3.906		787	.440	2.75		
1530	38.2	1.2	12.30	5072	1072	.7953	3.902		.785	.440	3.01	.06	.055
1545	39.7	1.2	12.80	5060	.1060	7941	3.896		.782	.439	3.10	.09	.055
1600	41.2		13.30	5045	.1045	.7926	3.887		.778	.438	3.19	.09	.055
1615	43.1		13.72	5031	.1031	.7912	3.881		.775	.437	3.25	.06	.036
1628				5018	.1018	.7899	3.875		.773	.43	3.30	.05	.035
1648	44.6		14.40	5000	.1000	.7881	3.866		.769	.435	3.43	.13	.059
1700	45.5		15.10	4189	.0983	.7870	3.861		.766	.434	3.51	.08	.062
1719	47.6		15.45	4182	.0982	.7863	3.858		.765	.433	3.62	.11	.052

Continuous Loading Test #9 — 24 March '59

Rate = 1.32 TSF/Hr.

Initial Meas.
Can #66
Tare: 13.0658
+Wet: 25.2785
+Dry: 21.5965
W = 43.1%

Time	Press PSI	(−) Corr.	Press TSF	Dial	Dial in	Ht in.	Vol. in³	V_s	$e=\frac{V}{V_s}-1$	$n=\frac{e}{1+e}$	Perm Gage	ΔQ cc	K $\frac{cm}{sec}\times10^{-6}$
0908	.3	?	.05	17120	.3520	1.0065	4.938	2.303	1.144	.533			
0910	.5	0	.07	17075	.3475	1.0020	4.916		1.135	.532			
0912	.6	0.1	.08	17010	.3410	.9955	4.884		1.121	.529			
0917	.9	0.1	.20	16070	.3270	.9815	4.815		1.091	.522			
0920	1.1	0.2	.22	15180	.3186	.9725	4.771		1.072	.517			
0923	1.3	0.2	.29	15108	.3108	.9653	4.736		1.056	.514			
0931	1.8	0.3	.43	14133	.2933	.9478	4.650		1.019	.505			
0937	2.1	0.4	.50	14035	.2835	.9380	4.602		.998	.499	.38		
0941	2.4	0.4	.60	14000	.2800	.9345	4.585		.990	.497	.40	.02	.043
0946	2.7	0.4	.71	13144	.2744	.9289	4.557		.979	.495	.41	.01	.018
0952	3.1	0.5	.80	13074	.2674	.9219	4.523		.964	.491	.42	.01	.008
1004	3.9	0.5	1.08	12162	.2562	.9111	4.468		.940	.485	.43	.01	.017
1010	4.3	0.6	1.18	12109	.2509	.9054	4.442		.929	.482	.47	.04	.059
1017	4.7	0.6	1.29	12060	.2460	.9005	4.418		.918	.479	.53	.06	.047
1030	5.8	0.6	1.63	11172	.2372	.8917	4.375		.900	.474	.61	.08	.054
1045	6.9	0.7	2.00	11087	.2287	.8832	4.333		.881	.468	.72	.11	.074
1100	8.0	0.7	2.40	11011	.2211	.8756	4.296		.865	.464	.83	.11	.073
1115	9.2	0.8	2.72	10140	.2140	.8685	4.261		.850	.459	1.52	.69	.084
1236	15.3	0.9	4.76	9386	.1886	.8431	4.136		.796	.443	1.70	.18	.072
1300	17.3	0.9	5.41	9032	.1832	.8377	4.110		.785	.440	2.45	.75	.079
1430	24.3	1.0	7.22	8060	.1600	.8205	4.025		.748	.428	3.20	.75	.077
1601	31.3	1.0	10.07	7129	.1529	.8074	3.961		.720	.419	3.43	.23	.073
1630	33.4	1.1	10.75	7094	.1494	.8039	3.944		.712	.416	3.63	.20	.074
1655	35.1	1.1	11.30	7067	.1467	.8012	3.931		.707	.414	4.29	.66	.072
1819	40.8	1.2	13.18	6184	.1384	.7929	3.890		.689	.408	4.71	.42	.089
1902	41.0	1.2	13.25	6174	.1374	.7919	3.885		.687	.407	5.62	.91	.094
2030	41.0	1.2	13.25	6165	.1365	.7910	3.881		.685	.407	5.72	.10	.091
2040	41.0	1.2	13.25	6165	.1365	.7910	3.881 3.890		.685	.407	5.82	.10	.091
2050	41.0	1.2	13.25	6165	.1365	.7910	3.885		.685	.407	5.92	.10	.091
2100	41.0	1.2	13.25	6165	.1365	.7910	3.881		.685	.407			

Final Meas
Can #47
Tare: 9.7238
+Wet: 140.5720
+Dry: 108.9952
W = 31.8%
V_{OL} =